Report on

IRRIGATION REQUIREMENTS AND AVAILABLE WATER RESOURCES

WAIMANALO IRRIGATION SYSTEM

Hawaii Irrigation Authority

Territory of Hawaii

1956

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Manager-Chief Engineer

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INTRODUCTION

To serve the farm lands being developed by the Territory of Hawaii at Waimanalo, Oahu, for its projected 25-year period of operation, it is necessary for the Hawaii Irrigation Authority to acquire an adequate source of water supply by long-term lease, by outright purchase or by condemnation. The major sources of supply are the surface and ground waters in upper Maunawili Valley and the Kawainui Swamp in Kailua, respectively owned by or under the control of the Kaneohe Ranch Co., Ltd. and the Castle Estate. The other sources of water available for irrigation at Waimanalo, which are owned by the Territory except for some existing "kuleana" rights, include the Waimanalo Lagoon, Waimanalo Stream and ground water in the "ahupuaa" of Waimanalo. These Waimanalo sources of water, even if combined, would not be sufficient to supply Waimanalo's needs and their value lies in furnishing water to supplement one of the major sources of supply from either Maunawili Valley or Kailua.

At the present time, the Authority is getting its water for the Waimanalo irrigation system from a ditch and flume system in upper Maunawili Valley (supplemented by water from Waimanalo Stream) which obtains its water from four tunnels, several springs and by the diversion of the surface flow of various streams. The available records (1924 to 1941) indicate that during extreme droughts the flow from upper Maunawili Valley may be reduced to a low of 1.3 million gallons per day. However, the "dependable low flow" is estimated to be 1.8 million gallons per day. "Dependable low flow" in this instance is defined as the lowest flow which occurs in four out of five years except for an occasional isolated day or two.

The Authority currently purchases the water in Maunawili Valley from the Kaneohe Ranch Co., Ltd. on a month-to-month basis for $666.67 per month. Since the Kaneohe Ranch Co., Ltd. has indicated a reluctance to enter into a long-term agreement with the Authority for the use of this water, it appears necessary for the Territory to develop another major source of water supply or to institute eminent domain proceedings to acquire the Maunawili Valley source if it is determined that this source is the best one for the Waimanalo irrigation system.

Historical

The Waimanalo Sugar Co. operated a sugar plantation at Waimanalo during the period 1878 to 1947 with a maximum of about 2600 acres in cane, most of which was on lands leased from the Territory of Hawaii. The water for irrigation was obtained from the combined sources of upper Maunawili Valley, Waimanalo Stream, Kawainui Swamp and the Waimanalo Lagoon. Water from upper Maunawili Valley was developed and brought to Waimanalo shortly after the plantation was started and this supply was further exploited in the period 1922-26 when the flume system was extended to divert more surface water and additional ground water in upper Maunawili Valley was developed. Pumps were installed to deliver water to Waimanalo from Kawainui Swamp through a new tunnel and flume system in 1923 and the Waimanalo Lagoon supply was developed at about the same time. The Waimanalo Stream, which supplemented the flow of the Maunawili Ditch system, furnished only a small amount of water for the plantation and, accordingly, was not a significant contributor to the irrigation water supply for Waimanalo. The mean quantitites of water delivered annually to

Waimanalo for irrigating sugar cane from the three major sources of water supply during the period of record, 1924 to 1941, are shown below:

Kawainui Swamp	1,058 million gallons per year
Upper Maunawili Valley . . .	630 million gallons per year
Waimanalo Lagoon	501 million gallons per year

In 1947 the Waimanalo Agricultural Development Company, Ltd. acquired the land and water leases from the Waimanalo Sugar Co. when the plantation was liquidated, and subsequently leased about 900 acres to farmers for diversified agriculture under short-term agreements. The Development Company operated the irrigation system but performed only the minimum amount of maintenance work needed to keep the system in operation. The Company discontinued using the Kawainui and Lagoon water sources and relied solely on the upper Maunawili Valley water supply as supplemented by the Waimanalo Stream. These sources proved inadequate during the dry years, particularly in 1953, for the 900 acres under lease and the additional estimated 140 acres farmed on a share-crop basis.

The Hawaii Irrigation Authority took over the operation of the Waimanalo irrigation system on November 22, 1953 when the lease to Waimanalo Agricultural Development Co., Ltd. covering the Territorial land and the irrigation system in Waimanalo expired. Since that time the Territory has been in the process of subdividing and selling small farm lots (averaging about 9 acres) to qualified farmers under the provisions of the Bankhead-Jones Farm Tenant Act. To date the Territory has subdivided and sold 351 acres in small farms of which 39 acres are being used as chicken ranches or as piggery farms with a minimum need for irrigation water.

Development of Waimanalo Farm Area

Until the Territory completes firm subdivision plans, it is not possible to determine accurately the acreage to be irrigated. The Authority has estimated that approximately 1200 acres of farm lots must be included in the project to make the irrigation system self-supporting. Recent information indicates that the Territory plans to subdivide a total area of approximately 1400 acres of which an estimated 300 acres will be in chicken farms or pig ranches requiring only a limited amount of water and 1000 acres will be planted in diversified crops requiring normal amounts of irrigation water. The remaining 100 acres will include the land required for residential and farm building purposes and the waste gulch areas.

ESTIMATES OF ULTIMATE WATER REQUIREMENTS WAIMANALO IRRIGATION SYSTEM

Discussion of Water Use Records

Although an irrigation system has been operated in Waimanalo for small-scale farming since 1947, there is a dearth of reliable data on the amount of water required for growing crops in that area. During the period that the Waimanalo Agricultural Development Co., Ltd., operated the system, 1947-1953, there were neither accurate measuring devices for determining the amount of inflow water to the reservoirs nor was the full amount of water supplied to the farmers for irrigation shown by their water sales records. The rate schedule included an acreage charge of $2.00 per acre per month which permitted a use of 25,000 gallons per acre per month without additional charge. Records of water sales, therefore, show only the amount of water used in excess of 25,000 gallons per acre per month. Additionally, no record was maintained

of the water used by the share-crop farms which included about 140 acres or about 12% of the total area. An analysis of water usage by twelve of the highest water using farms show that an average of 2,8 acre-inches of water per acre per month was supplied to those farms during the four-month period, April through July, in the very "dry" year of 1953. The comparable figure for the "wetter than usual" year of 1954 was 0.9 acre-inches. These figures reflect the wide variations in water usage at Waimanalo due to differences in total annual rainfall.

Good records of the water supplied to farmers in the Waimanalo area have been kept by the Authority since it took over the operation of this system on November 22, 1953. However, these records, like those of the Waimanalo Development Company, can not be considered entirely reliable for estimating future water requirements because they were obtained during a period of disturbed farm tenure. Since the end of the year 1953 considerable farm land in Waimanalo has been either fallow or not intensively cultivated and irrigated because many holders of revocable permits relinquished them or did only part-time or no farming pending the subdivision and sale of the farm lots. As an illustration of this situation, surveys of land usage during a 20-month period, March 1955 to October 1956 for which records are available, showed that on an average only 35% of the total area at Waimanalo assessed an acreage service charge for irrigation was actually under cultivation and irrigation. By comparison, a survey of 14 representative farms, which were farmed on a full-time basis, showed that an average of 51 percent of the assessed acreage of those farms was under irrigation during this same 20-month period. Because of this farm tenure situation overall records of water deliveries in Waimanalo

since the Authority has operated the irrigation system must be used with considerable discretion in projecting future water requirements.

Exhibit I shows various data on the operation of the Waimanalo water system for the calendar years 1954, 1955 and for ten months of 1956. These data include, among others, the monthly figures for assessed area, total water delivered to farm turnouts, water delivered per assessed acre, water delivered per irrigated acre, acreage irrigated, the water delivered each month as a percentage of the total amount of water delivered per year and monthly totals of rainfall. It will be noted that the water delivered per acre per month based on the total assessed area (Column 8) ranged from 0.006 acre-inch to 1.25 acre-inches. The mean was 0.50 acre-inch per month. As pointed out heretofore these water delivery figures were obtained during a period of disturbed land tenure and, therefore, are not reliable for use in estimating the future water requirements of the Waimanalo area without considerable adjustment.

In an effort to establish more valid data for estimating water requirements for the farm lot area in Waimanalo, water delivery records of 14 representative farms have been analyzed for the 12-month period, November 1955 to October 1956. These 14 farms were chosen by the manager of the Waimanalo irrigation system on the basis of his familiarity with the farming program there. They were selected as typical farms, representative of the total farm area then included in the irrigation system. Factors considered in their selection were variations in soil and rainfall conditions, diversification of crops and different farming methods practised in cultivating and irrigating crops.

The water deliveries and other data pertaining to these 14 farms for this 12-month period are shown in Exhibit II. The rainfall during the 12-month period was 53.39 inches or 124 percent of the long-term mean rainfall for the Waimanalo area. However, except for the months of December 1955 and October 1956, when heavy rainfall occurred, the monthly rainfall pattern during this analysis period was comparable to the long-term average. The total mean assessed area of the 14 farms was 132 acres, of which 122 acres was considered irrigable and 65 acres (average) were irrigated during the 12-month period.

It will be noted that water deliveries based on assessed acreage (Column 11) ranged from a low of 0.016 acre-inch per acre per month to a high of 1.37 acre-inches per acre per month with the mean delivery being 0.64 acre-inch per acre per month. The comparable figures based on the irrigated area (Column 13) were 0.037, 2.73, and 1.27 or almost exactly double that of the assessed acreage figures. It will be further noted that the average acreage under irrigation during this period (Column 6) was 50 percent of the total assessed area, ranging from a low of 42 percent in January to a high of 55 percent in June and November.

Water Requirements -- Theoretical Approach

As a check on the water requirement figures obtained through the actual operational records of the Waimanalo system, a theoretical approach was tried using various empirical formulas developed by the Bureau of Reclamation and the Department of Agriculture in their work in the western part of the United States. The methods used were (1) Lowry-Johnson Consumptive Use Method, (2) Thornthwaite Method of Evapo-transpiration, and (3) Blaney-Criddle Consumptive Use Method.

These formulas, in general, utilize similar data such as temperature, effective rainfall, length of daylight hours and diversification of crops although each formula treats the data slightly different. These methods have received considerable validity for use in estimating water requirements for diversified crops in the seventeen western states. The validity of their application to Waimanalo, however, is subject to some question because of differences in local conditions such as higher humidity, more persistent winds, variable rainfall, variations in soils and longer or continuous growing season. The results obtained by applying these three formulas to Waimanalo for the 12-month period, November 1955 through October 1956, are shown in Table I below:

TABLE 1
Estimates of Water Requirements--Theoretical Approach

	Consumptive Use Requirement per Year Acre-Inches	Crop Requirement* per Year Acre-Inches
Lowry-Johnson	38.54	12.87
Thornthwaite	43.96	18.88
Blaney-Criddle	39.30	14.63
Mean	40.60	15.46

*Crop requirement is equal to the consumptive use requirement less the effective rainfall.

This mean theoretical figure for crop requirement, 15.46 acre-inches per acre per year, is higher than the actual mean farm delivery figure of 15.20 acre-inches per irrigated acre per year found for the 14 representative farms in Waimanalo covering the same 12-month period in 1955-56 (Exhibit II, Column 13). Ditch and furrow losses on each farm due to percolation and runoff must be added to the theoretical crop requirement figure to obtain the

estimated farm diversion requirements for comparison with the operating data of the 14 farms.

For conditions existing at Waimanalo, it is estimated that the water losses below the farm diversion points will average 40 percent. Applying this percentage to the mean crop requirement figure obtained by the three formulas we find the theoretical farm diversion requirement to be 25.8 acre-inches, which is 10.6 acre-inches, or 69 percent higher than the actual water deliveries made to the 14 farms in the 12-month period, November 1955 to October 1956. While this difference in water requirements is considerable, it can probably be attributed to the fact that the theoretical formulas can not be applied to the Waimanalo area without corrections because of the differences in climatical conditions existing between the western part of the United States and the Waimanalo area. Of particular significance are the greater variations in rainfall and temperature at Waimanalo where the temperature decreases and rainfall increases sharply in a southerly or inland direction across the farm lot area. The temperature data used in applying the formulas to Waimanalo were those recorded at the University of Hawaii Experimental Farm in the northeasterly section of the farm area and the rainfall data was from the Waimanalo office raingauge in the northwesterly section of the farm area. They do not accurately represent the mean temperature and rainfall of the composite area comprising the 14 farms. For these reasons, in particular, it can be expected that water requirements computed by the formulas will be too high. Exhibit III shows the locations of the 14 farms, rain gauging stations and mean annual isohyetal lines. Exhibit IV gives the monthly rainfall at the Waimanalo

office station for the period 1894 to 1950 and for the year 1955.

Evaluation of Methods

After careful analysis of the three different methods discussed above for estimating water requirements at Waimanalo, viz.,

(1) water deliveries to the entire Waimanalo farming area;

(2) water deliveries to 14 representative farms for a 12-month period; and

(3) theoretical results obtained from the three empirical formulas,

it is concluded that the data obtained from the water deliveries to the 14 representative farms for the 12-month period, November 1955 to October 1956, is the most valid for estimating future water requirements. The extension of the data obtained from the 14 farms to the ultimate farm area at Waimanalo has accuracy limitations inherent with any method employing "sample" data as a basis for making project estimates. It is believed, however, that this method offers the most reliable means available for estimating these future water requirements.

Water Requirement Figures

The three water use figures most significant in estimating ultimate water requirements at Waimanalo are (1) mean annual, (2) maximum monthly and (3) maximum seasonal (June through October). The mean annual water requirement is particularly needed to estimate pumping costs and revenues as a basis for making economic studies and for establishing water rates. Maximum daily requirements for irrigation, while of value, are not too

significant inasmuch as the irrigation system includes four small reservoirs in Waimanalo with a total capacity of several days storage which can adequately handle daily fluctuations in water demand. The maximum monthly water requirement, on the other hand, is highly useful in estimating irrigation requirements and in determining the adequacy of available water resources. It is especially convenient because available records of water use, water supply and rainfall are normally reported by months. The maximum seasonal water requirement figure is important in determining the water required and the adequacy of available water resources over the "dry" summer period. It is significant, particularly, if primary water storage is available at the water source.

Area To Be Irrigated

Based on partially completed plans of the Territory, the following estimate is made on the ultimate area to be included in the Waimanalo Farm lot subdivision.

TABLE 2
Estimated area to be included in the project

1.	Irrigable diversified farm area	1,000 acres
2.	Home and farm building sites, waste gulch land	100 acres
3.	Chicken farms and pig ranches	300 acres
	Total	1,400 acres

Inasmuch as the chicken farms and pig ranches will probably

use some irrigation water but less than the crop lands on an acreage basis, a factor of 1/3 is applied to the 300 acres of chicken farms and pig ranches. It is assumed that no irrigation water will be required for the 100 acres of home and farm buildings, and the waste gulch land. The area used for computing water requirements, herein referred to as the "equivalent crop area", thus becomes 1100 acres.

Factors Considered in Computing Water Requirements

As pointed out above, it is believed the data obtained from the 14 farms during the 12-month period, November 1955 to October 1956, are most reliable for estimating the ultimate water requirements at Waimanalo. Accordingly, these data are used in the calculations of water requirements below.

In any irrigation system such as the one at Waimanalo where reservoirs and ditches are unlined, considerable losses will occur due to seepage. No accurate measurements of such losses in the Waimanalo system have been undertaken but rough estimates can be made of water losses for the high water use months. During the summer months of 1955 and 1956, when all the available water from Maunawili Valley was brought into the system, including the flow of Waimanalo Stream estimated at 5.0 million gallons per month, reservoir and ditch losses ranged from a low of 64 percent to a high of 80 percent of the total input of water to the irrigation system. The lower percentage figure was obtained for the month with the highest farm water delivery--28.4 million gallons and the highest percentage figure was for the month with the lowest farm water delivery--14.9 million gallons. Inasmuch as maximum monthly deliveries of water will increase when the

Waimanalo farm area is fully developed, and since certain improvements in the distribution system to reduce seepage losses are contemplated, it is believed that future storage and distribution losses will be less than those obtained in 1955 and 1956. It is estimated that losses for the maximum consumption month can be eventually reduced to at least 55 percent. If the Kawainui Swamp is utilized as the source of water for Waimanalo, further reduction in water losses can be effected since pumping can be so controlled that only a minimum use of the reservoirs in Waimanalo will be required. This will permit water levels in the reservoirs to be maintained lower with resulting reduction in seepage losses. It is estimated, therefore, that reservoir and distribution ditch losses for the Waimanalo system using the Kawainui Swamp as the source of water will approximate 50 percent of the total water pumped for the maximum month and 65 percent for the average year. It is believed that these figures are conservative and that any variations therefrom are more likely to be lower than higher.

Estimated Water Requirements Based on 14 Representative Farms

Estimates of water requirements for the 1100 equivalent crop acres at Waimanalo in the computations below are based on data obtained from the 14 representative farms in 1955-1956, as shown on Exhibit II.

TABLE 3
Estimated Water Requirements--Average Year

	Per Irrigated Acre		Annual Total for Irrigation System
	Acre-Inches	Million Gallons	Million Gallons
a. Farm Diversion Requirements (assuming an average of 50 percent of the 1100 acres of			

	Per Irrigated Acre		Annual Total for Irrigation System
	Acre-Inches	Million Gallons	Million Gallons
the equivalent crop area will be irrigated in any one year)	15.2	0.413	227
b. Diversion Requirements at Source (assuming 65 percent for reservoir and ditch losses)	43.4	1.18	649

The above figures, based on data from the 14 representative farms, indicate that during an average year, 649 million gallons of water would be required from the source, and that of this amount 227 million gallons, or 35 percent, would be delivered to the farms through the farm diversion gates.

Exhibit II shows that the maximum monthly water required during the 12-month period (Column 13) was 2.73 acre-inches in July 1956 on an irrigated acre basis. The rainfall for this month was only 0.87 inches (Column 14). Under conditions of light rainfall, most of the precipitation is usually evaporated and only a portion of it is effective for plant growth. It is, therefore, estimated that the maximum farm diversion water requirements for crops per irrigated acre under Waimanalo farming practices in the driest months to be expected (assuming no effective rainfall) will average 3.00 acre-inches. Other data obtained in the operation of the Waimanalo irrigation system have been evaluated by different methods and all tend to substantiate the validity of the figure of 3.00 acre-inches as the maximum mean monthly farm diversion requirement per irrigated acre. Since a greater acreage is generally under irrigation in the summer months, which are usually the driest, it is assumed for design purposes that 60 percent of the

equivalent crop area will be under irrigation when the maximum monthly water requirement occurs.

TABLE 4
Estimated Water Requirements--Maximum Month

	Per Irrigated Acre		Maximum Month's Total For Irrigation System
	Acre-Inches	Million Gallons	Million Gallons
a. Farm Diversion Requirements (assuming 60 percent of the 1100 acres of equivalent crop area will be under irrigation)	3.00	0.081	53.5
b. Diversion Requirements at source (assuming 50 percent for reservoir and ditch losses)	6.00	0.163	107.0

On the basis of water usage figures obtained during the years 1954, 1955 and through October of 1956, and a study of the long-term rainfall records at Waimanalo exluding the "dry" years with a frequency occurrence of less than 1 in 5 years, the following estimate of maximum water requirements for the principal growing crop season, June through October, is made, assuming that on an average 55 percent of the irrigable area will be under irrigation:

TABLE 5
Estimated Seasonal Requirement--Maximum Season

	Monthly Total per Irrigated Acre		Maximum Seasonal Total for Irrigation System
	Acre-Inches	Million Gallons	Million Gallons
a. Farm Diversion Requirements (assuming 55 percent of 1100 acres of equivalent crop area will be irrigated)			
2 months	3.00	0.082	98.6
1 month	2.60	0.071	42.7
2 months	2.20	0.060	72.2
Total	-	-	213.5
Mean per month	2.60	0.071	42.7

(Continued)

	Monthly Total per Irrigated Acre		Maximum Seasonal Total for Irrigation System
	Acre-Inches	Million Gallons	Million Gallons
b. Diversion Requirements at Source (assuming reservoir and ditch losses to be 55 percent)			
2 months	6.67	0.181	219.0
1 month	5.78	0.157	94.9
2 months	4.89	0.133	160.6
Total	-	-	474.5
Mean per month	5.78	0.157	95.0

The estimate of water required in the above table is based on an assumed minimum of approximately 6 inches of rainfall during any 5-month "dry" season. The 59-year record of the Waimanalo Office rainfall station shows that there was at least six inches of rainfall during each 5-month summer period, June to October, in 48 of the past 59 years. This represents a frequency ratio of 4.4, well within the assumed criterion of assuring adequate water to meet all irrigation needs in at least four out of five years. Therefore, on the basis of the data obtained from the fourteen representative farms as shown in Tables 4 and 5 above, the irrigation needs of the Waimanalo farm lots would be 107.0 million gallons of water during the "maximum month" and an average of 95.0 million gallons of water per month during a "maximum irrigation season". In evaluating a source, or sources, of water supply for the Waimanalo system, it is essential to consider any existing or developable primary storage at the source. Without storage the source of supply would have to be able to meet the maximum months irrigation requirements during any month of the year. With adequate storage the water source would only have to supply the maximum seasonal requirement less the quantity available from prior storage.

Waimanalo Stream--Supplementary Source

Since water from Waimanalo Stream will be available to the Waimanalo irrigation system irrespective of which primary source of water supply is utilized, the above figures of water requirements must be reduced by the amount of water available from the Waimanalo Stream. Available records indicate that the minimum flow of this stream was 0.30 million gallons per day (9.0 million gallons per month) and that the mean flow during 5-month "dry" periods was about 0.33 million gallons per day (10.0 million gallons per month) for the period 1924 to 1941. In 1941 the City and County of Honolulu completed a tunnel at elevation 620' in the mountain area above the Waimanalo Stream, which is reported to currently produce approximately 500,000 gallons of water per day. While there are no records available for the discharge of the Waimanalo Stream since 1941, it is believed that this tunnel has reduced the flow of the Waimanalo Stream and a quantity of 200,000 gallons per day is assumed as a correction factor. The following estimates for the discharge of the Waimanalo Stream are made:

TABLE 6
Estimated Flow of Waimanalo Stream

Period	Million Gallons per Month
Minimum flow for driest month	3.0
Mean flow for driest five months	4.0
Average Year:	
Jan., Feb., Mar., & Dec.	8.0
Apr., May, Oct., & Nov.	6.0
June, July, Aug., & Sept.	5.0

Final Estimate of Ultimate Water Requirements

As previously noted, the basic consideration in the selection of the 14 representative farms was to get a sample cross-section of the farm lands then in the irrigation system insofar as soil conditions, rainfall, diversification of crops and differences in farming practices for cultivation and irrigation were concerned. While it is believed that the 14 farms accurately represent the considerations specified for their selection, it is felt that the farms on these 132 acres, comprising the 14 farms, may not be entirely typical of a cross-section of all the farmers who will occupy the ultimate farming area at Waimanalo. None of the farmers selected were considered to be "failures" (although some were not necessarily operating at a profit) and their average ability is probably higher than will be the average ability of all the farmers to be ultimately located in Waimanalo. Further, it is believed that the mean rainfall will be higher and the mean temperature lower for the 1100 equivalent crop acres than for the corresponding means of the composite area of the 14 farms. For these reasons it is believed that estimated ultimate water requirements calculated on the basis of a straight area ratio will be too high. Accordingly, an arbitrary correction factor of 15 percent has been applied to the estimated water requirements shown above for the 1100 equivalent crop acres.

Adjusting the water requirement figures above for this 15 percent correction factor, the final estimates of farm diversion requirements and water supply diversions are obtained as shown in Table 7 below:

TABLE 7
Final Estimates of Water Requirements--1100 Acres

	Million Gallons Year	Month	Day
A. Farm Diversion Requirements			
1. Average year	193	16.1	0.54
2. Maximum month	-	45.5	1.52
3. Mean per month - maximum 5-month season	-	36.3	1.21
B. Primary Water Source Diversion Requirement -- either 1 or 2 below			
1. Maunawili Valley (no primary storage)			
a. Average year	476	39.7	1.32
b. Maximum month	-	88.0	2.93
c. Mean per month--maximum 5-month season	-	88.0	2.93
2. Kawainui Swamp (primary storage)			
a. Average year	476	39.7	1.32
b. Maximum month	-	88.0	2.93
c. Mean per month--maximum 5-month season	-	77.5	2.58
C. Secondary Source Diversion Requirements			
1. Waimanalo Stream			
a. Average year	76	6.3	0.21
b. Maximum month	-	3.0	0.10
c. Mean per month--maximum 5-month season	-	4.2	0.14

POTENTIAL WATER RESOURCES

While there is considerable hydrologic data available on the water resources which could supply the Waimanalo irrigation system, some of these data have only limited usefulness because of their short years of record. Changes in water diversion works, and other operational changes have tended to invalidate certain stream flow and pumping records. Other data have accuracy limitations. Nevertheless, the information available is adequate, if properly correlated and evaluated, for making a reasonable estimate of the quantity of water that can be diverted from the major sources of supply.

The data used for making these estimates have been obtained from the records of the Waimanalo Sugar Company, Kaneohe Ranch Co., Ltd., U. S. Geological Survey, the U. S. Weather Bureau, and Hawaii Irrigation Authority. The type of data, periods of record and their sources are shown below:

Data Used in Evaluation of Water Sources

1. Flow records of Maunawili Ditch, 1913 to 1916 and 1924 to 1941. U. S. Geological Survey and Waimanalo Sugar Company.

2. Flow records of Waimanalo Stream, 1924 to 1941. Waimanalo Sugar Company.

3. Pumping records, pondlevels and salt determination of Kawainui Swamp, 1924 to 1941. Waimanalo Sugar Company.

4. Pumping records of Kawainui Swamp, 1956. U. S. Geological Survey and Kaneohe Ranch Company, Ltd.

5. Pumping records of Waimanalo Lagoon, 1924 to 1941. Waimanalo Sugar Company.

6. Flow records of streams in Maunawili Valley, 1913 to 1916, 1922 and 1956. U. S. Geological Survey and Waimanalo Sugar Company.

7. Rainfall records as follows:

a. Maunawili Ranch Station, No. 787, 1895 to 1955, U. S. Weather Bureau and Kaneohe Ranch Co., Ltd.

b. Mt. Olympus Station, 1927 to 1943, U. S. Weather Bureau.

c. Konahuanui Station No. 789, 1927 to 1945, U. S. Weather Bureau and Board of Water Supply.

d. St. Stephens Seminary Station No. 788, 1943 to 1955, U. S. Weather Bureau.

e. Kawailoa Girls School Station No. 790, 1951 to 1955, U. S. Weather Bureau and Kawailoa Girls School.

f. Waimanalo Pump (at Kawainui Swamp, Kailua, Oahu), 1926 to 1934, Waimanalo Plantation records.

g. University of Hawaii Experimental Station at Waimanalo, 1950 to 1955. U. S. Weather Bureau and University of Hawaii Experimental Station.

h. Waimanalo Office, No. 794, 1894 to 1955. U. S. Weather Bureau and Hawaii Irrigation Authority.

i. Maunawili Reservoir, Waimanalo Irrigation System, 1955. Hawaii Irrigation Authority.

8. Staff reports, correspondence and miscellaneous file records. C. Brewer & Co., Hawaii Irrigation Authority.

Water Available from Upper Maunawili Valley

In Exhibit V are shown monthly deliveries of water to the Waimanalo irrigation system from the Maunawili Ditch during the period 1927 to 1941. Inasmuch as there usually was an excess of water in the winter or rainier months, the full flow of the Maunawili Ditch was not needed throughout the year for irrigation at Waimanalo. The excess water was discharged through turnout gates in Maunawili Valley before reaching the weir measuring station in Waimanalo at Aniani Nui Ridge. For this reason, only those monthly totals which are indicated by inspection as representative of the full flow of the Maunawili Ditch have been included in Exhibit V. It will be noted that

there were only two months with a flow of less than 55 million gallons and five months when the flow was less than 60 million gallons.

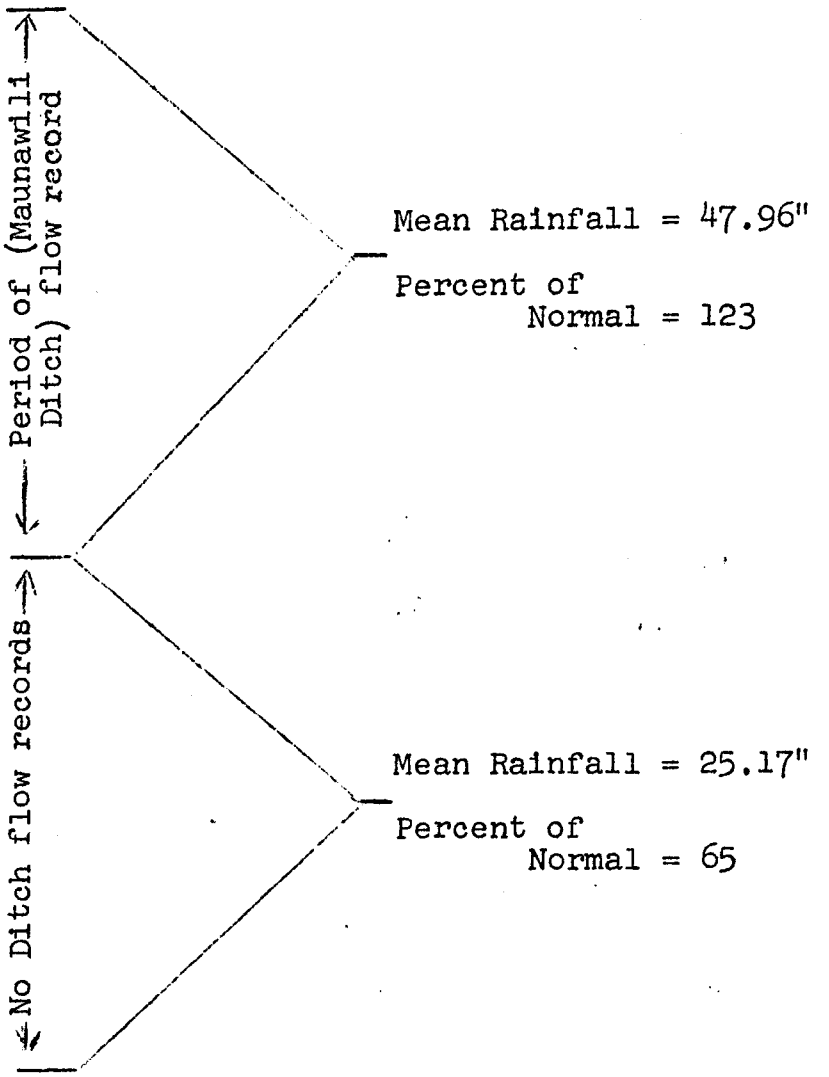
In the period 1922-1926 the Maunawili Ditch was extended and additional ground water was developed. Because of this situation only the records subsequent to 1926 are useful in estimating the flow in the Maunawili Ditch as of today. It might be possible to increase the present quantity of water diverted from upper Maunawili Valley by further tunneling but the increase would be small and it is not believed such improvements would be economically justified.

An inspection of the Maunawili Ditch daily flow records shows that the minimum flow of 1.50 million gallons per day occurred in December 1933. The next lowest minimum flow of 1.70 million gallons per day was obtained twice, in September and October 1929. The records also show that the minimum 4-month mean flow was 1.80 million gallons per day.

As a means of determining if these "low flows" of record are the minimum flows to be expected from the upper Maunawili Valley, an analysis was made of the rainfall records of the Maunawili Ranch rainfall station No. 787 to compare the rainfall during the period 1827-1941 with the long term record of this rainfall station. The monthly records of rainfall for the Maunawili Ranch station for 59 years of record, 1895 to 1955, are shown in Exhibit VI. From these records, the rainfall for the seven months, April to October, have been analyzed for the years 1927 to 1955 and compared with the long-term record of these months for this station. The results are shown in Table 8.

TABLE 8
Record of Rainfall--Maunawili Ranch Station No. 787
Elevation 250 feet
(7-month periods-- April to October inclusive)

	Inches of Rainfall	Percent of Normal
1927	58.75	151
1928	40.54	104
1929	26.18	67
1930	44.95	116
1931	46.84	120
1932	43.86	113
1933	21.76	56
1934	47.47	122
1935	45.78	118
1936	60.45	155
1937	48.40	124
1938	58.94	152
1939	59.70	154
1940	58.47	150
1941	57.35	147
1942	43.39	112
1943	38.58	79
1944	n o r e c o r d	
1945	32.54	84
1946	11.00	28
1947	17.50	45
1948	20.65	53
1949	9.98	26
1950	24.03	62
1951	21.79	56
1952	5.31	14
1953	n o r e c o r d	
1954	50.84	131
1955	26.42	68



Mean rainfall, April to October, 59 years of records, (1895 to 1955) = 38.89"

It is evident from Table 8 that the Maunawili Ditch flow records, 1927 to 1941, are not representative of "normal" flow conditions inasmuch as they were obtained during a "wet" cycle. The rainfall during the months April to October for the 15-year period, 1927-1941, was above normal for thirteen of the years

and below normal in two years, with a mean for the period of 123 percent of normal. Since rainfall was above normal during this period for which Ditch flow records are available, it can be concluded that these recorded Ditch flows are higher than normal and do not represent the minimum flows of the Maunawili Ditch.

Subsequent to 1941, beginning in 1945, a prolonged period of drought occurred. The mean rainfall for the 12-year period from 1942 to 1955, a period for which there are no Ditch flow records, was only 65 percent of normal. Four of these years received less than fifty percent of normal rainfall with the year 1952 having only 14 percent of the long-term average.

Table 8 shows that 12 years of the total 27 years of record since 1927 were below normal and 15 years had more than average rainfall. Of the sub-normal years, two occurred in the 15-year period 1927-1941, for which Ditch flow records are available; the others subsequent to that period. Based on a comparison of rainfall records, it is believed that the flow in Maunawili Ditch must have been lower in several of the years subsequent to 1941 than it was during the period of Ditch flow records, 1927-1941.

In evaluating these data in the light of the sub-normal rainfall during the period 1943 to 1955, it is estimated that: (1) the absolute minimum low flow of the Maunawili Ditch can be taken as 1.30 million gallons per day, and (2) the minimum flow which can be expected will be available four years out of five (except for occasional periods of a few days) is 1.80 million gallons per day. From these estimates it is found that the minimum monthly flow of the Maunawili Ditch which will occur in 4 years out of 5 is 54.0 million gallons. This is 34.0 million

gallons short of the estimated maximum monthly demand (88.0 million gallons) of the Waimanalo irrigation system after making allowance for the water available from Waimanalo Stream.

If the upper Maunawili Valley is to be continued as a source of water supply for the Waimanalo system, a supplementary water supply or supplies will be required to meet the estimated ultimate water demands of Waimanalo. The available supplementary water supplies include the Waimanalo Lagoon and the ground water in the "ahupuaa" of Waimanalo.

Water Available from Waimanalo Lagoon

The Waimanalo Lagoon is located in the northwesterly portion of the Territory's lands of Waimanalo, below the main road and near Bellows Field. It was used as a source of water for sugar cane in Waimanalo from about 1923 until 1946. Pumps boosted water up to a ditch and flume system which delivered the water to the cane fields. Pumping was limited by drawdown in the sump and by excessive increases in salt content. It was the least important of the three major sources which supplied water to the Waimanalo Sugar Company. During the 18 years of record in which this source was used, an average of 501 million gallons per year was pumped. An inspection of the pumping records for the period 1924 to 1941 indicates that the plantation was able to pump only about 50 million gallons of water per month during extremely "dry" months.

The principal sources of water for this lagoon are two branches of the Waimanalo Stream which collect surface water and ground water seepage as they flow from the mountains northward to the sea. It is thought that some ground water enters the lagoon directly in the form of springs or seeps. During the plantation days the normal flow of the Stream branches was considerably

increased by irrigation water finding its way to the Stream and by collection of mill water wastes. Sugar cane requires much heavier applications of water than are required for diversified crops so that any return irrigation water in the future will be considerably reduced.

It is not possible to make an accurate estimate of the contribution that was formerly made to the Lagoon by the return of cane irrigation water and mill water waste. No measurements of present-day flow in these Streams have been made except in one instance when instantaneous measurements of the flow in the main branches of the Waimanalo Stream were made on September 10, 1953 during a somewhat extended dry period. The measured combined flow in this instance was 0.490 million gallons per day. In evaluating the available information, the best estimate that can be made at this time for design purposes, which might be either high or low, is that a minimum of approximately 30 million gallons per month will be available from the Waimanalo Lagoon. This flow when added to the minimum monthly flow of the Maunawili Ditch indicates that these two sources of supply will furnish 84.0 million gallons per month. This quantity is almost equal to the 88.0 million gallons of water per month shown in Table 7 as the amount required to be diverted from a primary source of supply to meet the maximum month's demand for irrigation water. In this analysis it has been assumed that the maximum irrigation requirement month will occur at the same time that the minimum amount of water will be available from the various sources of water supply.

Ground Water--"Ahupuaa" of Waimanalo

The upper part of the "ahupuaa" of Waimanalo is criss-crossed with many volcanic dikes which form dike compartments not unlike an irregular honeycomb. Water in limited quantities can be obtained by sinking wells in these compartments. The amount of water obtained will depend on the size of the compartments, its watertightness and the amount of inflow of water from adjoining or nearby compartments when the water table is drawn down by pumping.

Only one producing well has been drilled in this dike complex. Tests have indicated a capacity of at least 175,000 gallons per day with a drawdown of 40 feet. The water table is 112 feet below ground level or 31 feet above sea level.

It is estimated that a good well in this area will produce 200,000 to 300,000 gallons of water per day or 6 to 9 million gallons of water per month. While it is believed this method of obtaining limited quantities of water for irrigating the Waimanalo lands would be successful, the costs of development and operation would be relatively high.

Water Available from Kawainui Swamp

Stream Discharge Measurements--Studies have been carried out to determine the inflow of water to the Kawainui Swamp for the purpose of estimating the amount of water that could be pumped from the Swamp for irrigating the farm lands at Waimanalo. The flows of the streams in Maunawili Valley have not been regularly gauged except for the three-year period, 1913-1916. A limited number of records are available giving various instantaneous flow measurements during the past 40 years

including three sets of instantaneous measurements made in recent months (1956).

Exhibit VII shows the minimum and mean discharges of the Streams which drain Maunawili Valley; the Kahanaiki, Pohakea, Kamakalepo, Kaimi, Makawao Streams and the Maunawili (Makawao) Ditch for the four summer months (June through September) of the years 1913, 1914, 1915 and for June 1916. These four months were selected because they are generally critical for both stream discharge and for maximum irrigation demand. The flows of all of the streams shown in Exhibit VII eventually reach the Kawainui Swamp; the Maunawili Ditch diverts water above the stream gauging points and delivers it to Waimanalo. It will be noted that the mean combined minimum daily discharge for the four-month summer periods shown, 1913 to 1915, was 3.19 million gallons per day in 1913 (Table A) and the lowest combined mean daily discharge of all the streams was 4.77 million gallons per day in 1915 (Table B). The rainfall for the four summer months in 1913 was 109 percent of normal and for 1915 it was 119 percent of normal.

A map showing the streams, mean annual isohyetal lines, and the locations of stream-gauging and rainfall measurement stations is included as Exhibit VIII.

Exhibit IX gives information collected in 1956 on instantaneous discharge measurements of streams in Maunawili Valley. Most of the stream measurements were taken at the same points in the streams as in 1913-1916. The discharge figures are not entirely comparable, however, because water used in the earlier years for irrigating rice, etc. in Maunawili Valley was generally estimated rather than actually measured, and, as previously

mentioned, more surface and ground water from Maunawili Valley was diverted into the Maunawili Ditch for use at Waimanalo subsequent to the period 1922-1926.

A summary of the pertinent flows of the Streams in Maunawili Valley for 1956 is shown in Table 9 below:

TABLE 9
Streamflow Measurements
for September 5, October 3, and November 14, 1956

	Stream Discharges in Millions of Gallons per day		
	Mean	Minimum	Maximum
Pohakeo Stream (including flow of Drainage Ditch)	0.155	0.114	0.212
Kamakalepo Stream	0.651	0.449	0.905
Kaimi Stream	0.503	0.457	0.527
Makawao Stream	1.26	1.15	1.32
Kahanaiki Stream (combined North and South branches)	0.370	0.330	0.449
Combined daily flow of above five Streams (not total of above figures)	2.93	2.65	3.41
Kahanaiki Stream - at New Kalanianaole Highway Bridge	0.739	0.453	0.976
Maunawili (Kailua) Stream - at Wong Leong's Ditch (including flow of Ditch)	2.54	2.33	2.92
Maunawili (Kailua) Stream - at New Kalanianaole Highway Bridge	2.84	2.55	3.41
Combined Kahanaiki and Maunawili Streams and Wong Leong's Ditch - at New Kalanianaole Highway Bridges	3.60	3.00	4.39

Based on periodic readings (approximately weekly) of the Maunawili Ranch rainfall station, the rainfall for periods of 10 to 18 days immediately preceding the days that the streamflow measurements were made is as follows:

Sept. 5 - 2.57 inches (18 days) = 95 percent of normal summer rainfall

Oct. 3 - 1.09 inches (14 days) = 52 percent of normal summer rainfall

Nov. 14 - 0.45 inches (10 days) = 30 percent of normal summer rainfall

The above percentages indicate that the streamflow measurements are probably below the average summer discharges of these streams and may approach the minimum "dry" weather flow of the streams. It will be noted that the combined mean flow of the five streams in Maunawili Valley (line 6 of Table 9) is 2.93 million gallons per day which is considerably below the similar figure of 4.77 million gallons per day obtained during the period 1913 to 1916 (Exhibit VII-B). Part of this difference is due to the increased diversion of water from Maunawili Valley by the Maunawili Ditch subsequent to 1922-1926 and part to the difference in rainfall. It will be noted also in Table 9 that the streamflow measurements in the lower reaches of the Kahanaiki and Maunawili Streams at the Kalanianaole Bridges are greater than the discharges measured higher up on these Streams. This indicates that these are "gaining" streams and that ground water contributes to their flows before they discharge into the Swamp.

Ground Water--An analysis of rainfall and stream discharge data for each of the watershed areas in Maunawili Valley shows considerable variations in the percentage of rainfall measured as stream flow at the stream gauging stations. The rainfall factor for each watershed was based on ischyetal lines developed by correlation of the records of nearby rainfall stations. The results obtained showed quantities of water unaccounted for,

ranging from 35.1 percent (Kaimi Watershed) to 78.8 percent (Pohakea Watershed). This wide percentage difference may be due in part to the difference in evapo-transpiration rates of the watersheds and by errors inherent with the correlation method used for computing rainfall, but the results suggest strongly that a considerable part of the rainfall on the Pohakea Watershed infiltrates to the water table. Other watershed areas, such as Kahanaiki with 74.7 percent unaccounted-for water, also indicate a high factor of infiltration. Some of this water undoubtedly enters the streams at lower elevations where the streambeds intersect the water table; the balance, or a portion of it, probably enters the Swamp as unmeasured ground water flow.

Correlation of rainfall and pumpage--In the studies of rainfall and stream discharges, an effort was made to develop a correlation between rainfall and pumpage from the Swamp by the Waimanalo Plantation Company during the period of record, 1924 to 1941, in order to obtain an estimate of the quantity of water that might be pumped from the Swamp as of today. The results obtained were not conlusive, probably because too many assumptions and correlations of data were required and too little factual information was available. The records of pumpage and pond levels of the Kawainui Swamp are considered to be reasonably accurate but the estimates of surface water inflow, ground water inflow, the evapo-transpiration rate of the Swamp area and the storage volume of the Swamp at different pond levels must be taken as approximate only since they necessarily are based on inadequate records, correlated figures or on assumed values.

The quantity of water required to meet the evapotranspiration needs of Kawainui Swamp is estimated to be 0.5 million gallons per day. At higher stage heights of the Swamp, this figure would be increased and it would possibly be less at stage heights below sea level. No reliable estimates can be made of the amount of ground water inflow to the Swamp, if any, or the amount of outflow as seepage from the Swamp. It is concluded, therefore, that analysis of the available streamflow records, rainfall records and related information will provide only an approximate answer for the quantity of water that can be pumped from the Swamp.

Estimate of Quantity of Surface Water--In Table 9 the combined mean flow of the Kahanaiki and Maunawili Streams at the Kalanianaole Bridges was found to be 3.60 million gallons per day for three measurements made in 1956 when rainfall was below normal. The comparable minimum flow was found to be 3.00 million gallons per day. While this minimum flow of 3.00 million gallons of water per day occurred during a subnormal rainfall period it probably is not the absolute minimum flow to be expected during a "dry" summer period. On the other hand, it probably is lower than the mean flow during a five-month "dry" summer period. Taking into account the evapotranspiration needs of the Swamp of about 0.5 million gallons of water per day and seepage losses, and allowing some credit for the inflow of unmeasured ground water into the Swamp, it is believed that in four years out of five a minimum mean quantity of 3.0 million gallons of water per day could be obtained from the Swamp during a five-month summer period.

Pumping Records - Kawainui Swamp--There are three sets of pumping records which can be evaluated for the purpose of estimating the quantity of water that could be pumped from the Swamp. These records must, however, be considered in the light of changed conditions before finally arriving at an evaluation of the Swamp as a source of water for the Waimanalo irrigation system.

(Analysis No. 1) In 1923 after the Waimanalo Sugar Company installed its pumping station in the Swamp, a 3-month test was made at a constant rate of pumping. A pump was started on May 22 with a pond level of 1.80 feet above sea level and the pumping was continued for 100 days, or until August 31, at a constant rate of 3.7 million gallons of water per day. A summary of the results is shown in Table 10 below:

TABLE 10
Pumping Test - Kawainui Swamp--1923

Date From	Date To	Days of Pumping	Millions of Gallons Pumped Total	Millions of Gallons Pumped Mean per day	Level of Pond Beginning	Level of Pond End of Period	Change in Pond Level
May 22	June 6	14	52	3.7	+1.80	+1.43	-0.37'
June 6	Aug. 4	59	218	3.7	+1.43	+0.09	-1.34'
Aug. 4	Aug.31	27	100	3.7	+0.09	-1.23	-1.32'
		100	370				-3.03'

The rainfall during the test period was about 62 percent of normal. This would indicate that with normal rainfall, and under the conditions then existing, a monthly mean of at least 4-1/2 million gallons of water per day could be pumped from the Swamp during a summer period starting with a pond level of

approximately 2 feet above sea level, and ending with a pond level not lower than 2 or 3 feet below sea level.

Since the extension of the flume system farther into Maunawili Valley and the development of additional ground water in the period 1922-1926 resulted in diverting an estimated one million gallons more water per day for delivery to Waimanalo, it can be assumed that as of today there would be about one million gallons less water available per day from Maunawili Valley to supply the Swamp than during the period of the test in 1923. It is estimated, therefore, on the basis of this test, that under normal rainfall conditions, a minimum average of 3-1/2 million gallons of water per day could be pumped during the maximum irrigation demand months, June to October, if adequate storage were provided in the Swamp. Under extremely "dry" conditions the average amount of water available from the Swamp might be reduced to 3.0 million gallons of water per day or less.

(Analysis No. 2) The Waimanalo Sugar Company used the Kawainui Swamp as its principal source of water supply from 1924 to 1947. During this period the Plantation pumped up to a maximum of 8 million gallons of water per day with two pumps, each rated at 4 million gallons per day. However, the number of hours the pumps operated was governed by the need of water for irrigation purposes and by the pond level and chloride content of the water. During the "drier" months the pumping had to be decreased as the pond level went down or the salt content increased. The records indicate that the pumps were stopped when the pond level reached about the minus 4-1/2 foot level. Normally, the salt content of the water ranged between 3 and 15 grains per gallon

although at low pond level under heavy pumping it occasionally exceeded 20 grains per gallon. Records of pumpage, pond levels and salinities for the eleven-year period, 1924 to 1934, and the monthly totals of pumpage for the years 1935 to 1941 (through June) are shown in Exhibit X.

In Table 11 are shown the quantities of water pumped for the 5 summer-month periods (June to October) for the years 1927 to 1940 and the rainfall for these months. The second column shows the total water pumped for the 5-month periods whereas the fourth column represents the mean quantity of water pumped per month for those months in which pumping was carried out continuously or nearly so. In periods when an adequate supply of water was available from the Maunawili Ditch or there was sufficient rainfall at Waimanalo, the pumps in the Kawainui Swamp were not operated. For this reason the figures in the fourth column represent more accurately the quantity of water available from the Swamp. It will be noted in Table 11 that in the year 1929, the mean pumpage for five months was 2.4 million gallons per day. The next lowest year was 4.0 million gallons per day in 1933. These also represent the years with the lowest rainfall. This would mean that in only one year of these fourteen years was the pumpage below the estimated requirement for the Waimanalo irrigation system--2.58 million gallons of water per day as shown on Table 6. Since this record of pumping occurred during a period when rainfall was higher than normal (Table 8), evaluation of this water supply must anticipate a higher frequency rate of years when the water available from the Swamp will average less than 2.58 million gallons of water per day during the summer season.

TABLE 11

Pumpage and Rainfall - Kawainui Swamp
For 5-Month Periods (June to October) - 1927 to 1940

Year	Total Pumpage June to October (Million Gallons)	Number of Months Pumps Operated at least 90% of Days in Month	Mean Pumpage for Months in Which Pumps Operated at least 90% of Days in Month (Million Gallons)		RAINFALL Maunawili Ranch Station	
			Month	Day	Total for 5-Month Period (Inches)	Percent of Normal
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1927	839	4	179	6.0	21.47	86.2
1928	776	5	155	5.2	23.50	94.4
1929	354	5	71	2.4	18.02	72.4
1930	649	3	216	7.2	37.21	149.5
1931	594	4	130	4.3	35.79	143.8
1932	1002	5	200	6.7	25.26	101.5
1933	595	5	119	4.0	15.34	61.6
1934	733	3	187	6.2	33.22	133.5
1935	696	3	217	7.2	36.79	147.8
1936	1057	4	236	7.9	42.75	171.8
1937	936	5	187	6.1	28.25	113.5
1938	768	3	206	6.9	34.02	136.7
1939	819	4	188	6.3	39.70	159.5
1940	818	4	190	6.3	25.30	101.6
Mean	760	4	177	5.9	29.76	119.6

NOTE: Pumps were not operated when sufficient rain occurred in Waimanalo or when the flow of the Maunawili Ditch was sufficient to meet irrigation needs.

An analysis of these pumping records in connection with the long-term rainfall records leads to the conclusion that a minimum average of 2.58 million gallons of water per day will be available during the summer periods in at least four years out of five--the criterion of water adequacy established for the Waimanalo irrigation system.

A more detailed study of the pumping records and pond levels of the 1927-1941 period as shown on Exhibit X indicates that when the pond level of the Swamp was at a stage height of 2 feet or more above sea level at the beginning of June, there was sufficient water available to meet the estimated future requirements of the Waimanalo irrigation system. Although Table 11 shows a deficiency of water for the year 1929, this was due to heavy pumping in April and May (193 and 181 millions of gallons respectively) which resulted in a stage level of only 0.60 feet above sea level at the beginning of June. Inasmuch as the Waimanalo irrigation system will require a relatively small amount of water prior to June of each year, there should not be any operational difficulties in starting the month of June each year with a stage height of at least two feet above sea level, provided the Swamp can be used as a primary storage reservoir.

(Analysis No. 3) During the past year the Kaneohe Ranch Co., Ltd. has endeavored to drain the Kawainui Swamp purportedly to reclaim some of the Swamp land for grazing and to minimize the mosquito problem in Kailua. To accomplish this the Ranch Company installed a large capacity low-head pump at the northwesterly corner of the Swamp and pumped into the Kawainui-Oneawa drainage canal which discharges into the northern tip

of Kailua Bay. The drainage ditches in the Swamp were cleaned out to some extent to facilitate drainage from the central pond section of the Swamp.

In August 1956, through the courtesy of the U. S. Geological Survey, the discharge rate of this pump was measured and a float with recorder was installed in the pump sump. By this method several months of pumping records have been obtained. The records are not complete due in part to mechanical failures of the recorder and in part to irregularity of pump operations necessitated by dredging work being carried out in the drainage ditches. The pumping data are shown in Table 12 below.

TABLE 12
PUMPAGE RECORD OF KAWAINUI SWAMP, OAHU
(August 8 to November 14, 1956)

Date	Pumpage in Million Gallons	Date	Pumpage in Million Gallons	Date	Pumpage in Million Gallons
Aug. 8	3.9 (4.94)	Aug. 28	2.6	Oct. 3	3.2(3.00)
9	7.8	29	3.1	4	4.1
10	7.0	30	4.4	5	3.4
11	5.5	31	4.0	6	3.1
12	5.1	Sept. 1	3.6	7	2.5
13	5.0	2	4.1		
14	4.4	3	3.1	10	7.2
15	3.7			11	4.8
16	3.7	5	3.0 (3.35)		
17	3.4	6	3.0	Nov. 4	9.5
18	4.8	7	3.4	5	7.4
19	4.2	8	2.3	6	7.3
20	4.1	9	2.2	7	8.2
21	3.8	10	2.0	8	6.7
22	3.3	11	2.6	9	6.2
23	3.2	12	1.7	10	4.5
24	3.2			11	4.9
25	3.3	26	2.8	12	4.7
26	3.1	27	3.6	13	4.4
27	3.3	28	2.3 (3.22)	14	4.4(4.39)
		Oct. 1	5.2		
		2	4.4		

The pumping record of Table 12 covers about 3-1/2 months starting in August, at a time when some stored water was still contributing to the total daily pumpage, even though the pumps had been operating for several months previously. Where no record of pumpage is shown in Table 12, it is due either to faulty records or because the pump was shut down temporarily. The pumping record indicates that storage withdrawal from the Swamp was gradually reduced during the first month after which the pumpage probably represents only the daily inflow of water to the Swamp. During the two weeks subsequent to September 12, the pumps cut in and out frequently each day, due apparently to rapid changes in the water level of the pump sump. It is not clear whether this was because of reduced inflow of water to the Swamp or because the drainage ditches were not sufficiently cleaned to permit proper drainage of the Swamp. The pump was shut down for about two weeks beginning October 14. An analysis of the pumping record of Table 12 leads to the conclusion that the Swamp, under drained conditions, cannot be depended upon to provide more than an average of 2 million gallons or less of water per day during "dry" periods.

The five instantaneous measurements made in 1956 of the combined flows of the Maunawili and Kahanaiki Streams are shown enclosed in parentheses in Table 12 for comparison with the corresponding daily pumpage. They indicate a reasonable correlation between inflow and pumpage. The rainfall during this 3-1/2-month period of pumping was, on the average, slightly above normal although "dry" periods of one or more weeks occurred during the pumping period.

The pumping records obtained during this Swamp drainage pumping period are not conclusive but they are helpful in indicating the quantity of water which could probably be pumped from the Swamp if no storage were maintained.

Salinities of the Kawainui Water Source--Various salinity samples have been taken at different points in the streams, in the Swamp and from the lower drainage ditches. Thus far, the samples in the streams and in the Swamp have all shown low salinities ranging generally between two and three grains of salt. Some of the samples taken in the lower drainage ditches were from stagnant water and were high in salinity. The salanity samples taken from the discharge line of the drainage pump averaged about 35 grains. This is thought to be due to salt water seepage from the nearby Kawainui-Oneawa canal.

Other Uses of Kawainui Swamp Water--The Honolulu Construction and Draying Company is taking some water from the upper end of the Swamp for its quarrying operations. It is reported that this quarry uses about one million gallons of water per day, primarily for the purpose of washing its rock aggregates. Most of the water drains back into the Swamp and is reused. It is not thought that the amount of water withdrawn and not returned to the Swamp is enough to materially affect the quantity of water available for pumping to Waimanalo.

Summarized Estimates Of Available Water--As stated above the various records of pumping from the Swamp are not adequate for making an accurate estimate of the quantity of water that can be obtained for the Waimanalo irrigation system,but since they are the best sources of information available they have been evaluated for the purposes of this report. The estimated

quantities of water that can be pumped from the Swamp, derived from the various stream flow and pumping records, are shown in Table 13 below.

TABLE 13
Summarized Estimates of the Quantity of Water Available From the Swamp based on Various Streamflow and Pumping Records

Type of Record	Estimated Mean Minimum Quantity of Water Available from the Swamp during a "Dry" Summer Season Million Gallons per Day
Stream Flow Records (Inflow of surface water)	3.0
Pumping Records--with storage	
Pumping Test-- 100 days in 1923	3.0
Irrigation Pumping -- 1927 to 1940	3.0 to 4.0
Pumping Record--without storage	
Swamp Drainage Period -- 1956	1.5 to 2.5

Table 13 above indicates that the Swamp, with storage, will provide the required mean summer flow of 2.58 million gallons of water per day for the Waimanalo irrigation system. On the other hand, the pumping records during the drainage period in 1956 indicate that the Swamp, if kept drained, will not provide an adequate water supply for the Waimanalo irrigation system.

Operation of the Swamp as a Primary Storage Reservoir--The Swamp, as a source of water supply, has always been operated with storage and probably could be used for this purpose by the Irrigation Authority. However, the Swamp when so used tends to create a mosquito problem for the people living

in the adjacent areas. This situation might become so acute that public opinion would react against the Authority if it were to store water in the Swamp. It is not known whether preventive measures for mosquito control could be carried out at an economical cost.

The Corps of Engineers proposes to develop the Swamp area as a flood prevention project to protect the Kailua residential and business areas. The plans call for maintaining the level of the Swamp at 2 feet above sea level as a water conservation measure. To implement this plan will require an appropriation from Congress and the turning over of title to the Federal Government of part of the Swamp area. It can not be said for certain that this flood prevention project will be constructed, but if constructed, it will not prevent the use of the Swamp as a source of irrigation water since the plans propose to maintain the water level in the Swamp above sea level.

COMPARISON OF COSTS--MAUNAWILI VALLEY-WAIMANALO LAGOON SUPPLY AND KAWAINUI SWAMP PUMP SUPPLY

As shown in Table 7 the 1100 equivalent crop acres to be irrigated at Waimanalo will require 88 million gallons of water per month (2.93 million gallons per day) in addition to the water available (3.0 million gallons per month) from the Waimanalo Stream during a month of maximum irrigation demand. This quantity of water, 88 million gallons per month, will have to be available during every such month of any year if primary storage is not provided whereas only an average of 77.5 million gallons of water per month (2.58 million gallons per day) will be required if primary storage is provided at the water source. Inasmuch as there is no primary storage for the Maunawili Valley flume system, the adequacy of this water source will depend on the minimum monthly stream discharges. (Daily fluctuations in stream flows will be "levelled out" by the terminal reservoirs in Waimanalo and, therefore, they are not critical in the evaluation of the Maunawili flume system.)

As noted on page 24 the records indicate that the Maunawili Ditch and flume system will only provide an estimated 54.0 million gallons of water per month during very "dry weather" conditions. To make up the deficiency in the Maunawili ditch system, it will be necessary to install a pump in the Waimanalo Lagoon to furnish an estimated additional 30 million gallons of water per month. This installation will require, in addition to the pump, the construction of a collection system and the installation of approximately 7800 feet of 8" discharge line to the Pump Reservoir. In lieu of installing a pump in the Waimanalo Lagoon, wells could be constructed in Waimanalo to

provide an equivalent amount of water. Since the capital costs and the annual charges for these two alternative installations are practically the same, the Lagoon Pump has been used in the cost computations below.

Estimates have been made of the costs of new construction, rehabilitation costs, annual amortization charges for repayment of capital costs within 25 years and the annual operating costs for both the Maunawili Valley-Waimanalo Lagoon and the Kawainui Swamp systems. In making these estimates, it was assumed that all flumes in both systems would have to be replaced once during the 25-year life of the project and that pumps, buildings, pipelines and other appurtenances would have a usable life expectancy of at least 25 years after their initial installation.

Pumping costs have been computed on the basis of water requirement figures shown in Table 14 below in accordance with Rate Schedule "D" of the Hawaiian Electric Company, Ltd.

For the purpose of estimating the purchase cost of the water from the two primary sources of supply, the prices paid heretofore by users of this water have been employed in the computation of annual operating costs. The purchase price of the Maunawili Valley water was $10,000 a year when this source was utilized by the Waimanalo Development Company. It was reduced to $8,000 per year when the Irrigation Authority took over the Waimanalo irrigation system, presumably for the reason that this water was then made available to the Authority on a month-to-month basis. The charge for the Kawainui Swamp water was $6 a million gallons with a minimum monthly charge of $360.00 when this source of water was used by the Waimanalo Plantation Company.

TABLE 14

Water Required for Waimanalo Irrigation System
in Millions of Gallons

Month	Farm Diversion	Estimated Ditch and Reservoir Losses (Percent)	Source Diversion	Water Requirement Per Month for Area Above Kailua Ditch	Water Requirement Per Month for Area Below Kailua Ditch	Available from Waimanalo Stream	Quantity of Water Required to be Booster Pumped	Quantity of Water Required to be Pumped from Kawainui Swamp
Jan.	2	80	10	3	7	8	0	2
Feb.	2	80	10	3	7	8	0	2
Mar.	5	77	22	8	14	8	0	14
Apr.	9	74	35	12	23	6	6	29
May	21	67	63	21	42	6	15	57
June	29	61	73	25	48	5	20	68
July	33	58	77	26	51	5	21	72
Aug.	33	58	77	26	51	5	21	72
Sept.	29	61	73	25	48	5	20	68
Oct.	16	71	55	19	36	6	13	49
Nov.	9	74	35	12	23	6	6	29
Dec.	5	77	22	8	14	8	0	14
Total	193	-	552	188	364	76	122	476

NOTE: Thirty-four percent of equivalent crop area estimated to be above the Kailua Ditch; the remaining sixty-six percent below the Kailua Ditch.

For the computations below, $10,000 a year for Maunawili Valley water and $6 a million gallons with a monthly minimum of $360.00 for the Kawainui Swamp water have been used.

Estimates of Capital Costs and Annual Operating Costs

The estimates shown below include only the costs of the construction of new facilities, the rehabilitation of existing facilities, amortization, power and other operations required to deliver the water to the terminal reservoirs in Waimanalo. They do not include the costs of water distribution to the farms, supervision and billing, and overhead.

TABLE 15
Capital Costs and Annual Operating Costs
Maunawili Valley-Waimanalo Lagoon Water Sources

Capital Costs		
Maunawili Valley		
Replacement of Flumes	$32,400	
Rehabilitation of Concrete Ditches	800	
Total, Maunawili Valley		$33,200
Engineering, Overhead & Contingency at 20%		6,640
Sub-Total, Capital Costs		$39,840
Waimanalo Lagoon		
2 - 350 GPM Pumping Units and Starters	$ 4,000	
Pump House and Sump	7,500	
Collection System	20,000	
Sheet Piling, Stopgate and Weir	10,000	
Discharge Line to Pump Reservoir-- 7800 feet of 8" CI Pipe	62,400	
Total, Waimanalo Lagoon		$103,900
Engineering, Surveys and Overhead at 15%		15,585
Sub-Total, Capital Costs		$119,485
Total of All Capital Costs		$159,325

TABLE 15 (Continued)

Operating Costs--Annual

Maunawili Valley and Waimanalo Lagoon

Labor	$ 2,800	
Materials	700	
Labor, Operation of Pumps	350	
Repairs to Pump, Labor and Parts	450	
Amortization of $159,325 at 6%	9,560	
Power Costs for Pumping--Average year 60 million gallons	1,176	
Estimated Purchase Price of Water Per Yr.	10,000	
Total Annual Costs		$25,036

Capital Costs and Annual Operating Costs
Kawainui Swamp Water Source

Capital Costs

Swamp Pump System

Dredging pond and canal, repairs to sump	$10,000	
2 - 1000 GPM Pumping Units & Starters	7,400	
Electrical work	1,000	
Pipe Connections at Pumping Station	1,500	
Rehabilitation of Pump House	2,500	
Remote Control System	1,200	
Venturi Meter	2,000	
Total Pumping Station		$25,600

Transmission System

2200 feet of 12" CI Pipe	$26,400	
Rebuilding 737 feet of wooden flume	10,700	
Rehabilitating Supply Ditch to Kailua Reservoir	1,500	
Rehabilitating Tunnel	500	
Total Transmission System		$39,100

TABLE 15 (Continued)

Booster Pump - Kailua Reservoir		
2 - 400 GPM Pumping Units and Starters	$ 4,200	
Pump Station Building	3,500	
Pipe and Electrical Work	1,000	
Venturi Meter	1,200	
2100 feet of 8" CI Pipe	16,800	
Total Booster Station		$ 26,700
Engineering, Surveys and Overhead at 15%		13,710
Total All Capital Costs		$105,110
Operating Costs--Annual		
Labor, Operation of Pumps	$ 1,200	
Maintenance Dredging	1,000	
Repairs to Pumps, Labor and Parts	600	
Transmission System Maintenance--Labor	1,200	
--Materials	300	
Amortization of $105,110 at 6%	6,307	
Power Costs for Pumping -- Average year		
Kawainui Swamp Pumps - 476 Million Gallons	6,725	
Booster Pump - 122 Million Gallons	3,000	
Purchase Price of Water at $6.00 per Million Gallons with a Minimum Monthly Charge of $360	4,560	
Total Annual Costs		$ 24,892

In the cost estimates above it will be noted that the capital expenditures for the Maunawili Valley-Waimanalo Lagoon system will be $159,325 and for the Kawainui Swamp system $105,110. The respective estimated annual operating costs will be $25,036 and $24,892. Since there is less than $150 difference between the two annual operating cost figures, this difference is not considered significant and it is concluded that there is no choice between the two potential primary sources of water supply for the Waimanalo irrigation system on the basis of annual operating costs.

SUMMARY AND CONCLUSIONS

Since the plans for developing the Waimanalo Farm Lots have not been completed to date by the Territory, it has been necessary for the Authority in preparing this report to make use of tentative development plans to estimate the areas of land which will ultimately require irrigation. Various methods have been employed for estimating irrigation requirements. The water use data obtained from the irrigation of the 14 representative farms during a 12-month period, 1955, 1956, are considered most reliable for determining ultimate water requirements. It has been found that water supply diversion requirements (exclusive of water supplied by the Waimanalo Stream) for the estimated 1100 "equivalent crop acres" will be 476 million gallons of water for the average year, 88.0 million gallons of water for the maximum crop requirement month and 77.5 million gallons of water per month for the maximum crop requirement season.

The stream discharge records of the Maunawili Ditch and flume system indicate that this source of water will supply only approximately 54.0 million gallons of water per month in "dry weather". In order to supply the maximum irrigation requirement of 88.0 million gallons of water per month, a supplementary source of water supply will be required. Either the Waimanalo Lagoon or wells in Waimanalo could be developed to supply this irrigation deficiency. The capital costs and annual operating charges for these alternative supplementary sources of water are estimated to be about equal.

The evaluation of the Kawainui Swamp as a source of water supply has been made by analyzing stream discharge measurements and records of past pumpages of water from the Swamp. The findings

show that the Swamp will not furnish the water required for irrigation at Waimanalo unless the Swamp is utilized as a primary storage reservoir in a manner comparable to its use in prior years. If adequate storage is provided the Swamp will supply the required water for the Waimanalo farm lots.

The estimates show that capital costs required to develop and rehabilitate the Maunawili Valley-Waimanalo Lagoon system would be more than those needed to develop and reactivate the Kawainui Swamp water source. The respective capital costs would be $159,325 and $105,110. The capital cost of the construction and rehabilitation of the Kawainui Swamp system is predicated on the installation of pumps at the existing pumping station location. If it is required by the owners of the Swamp that the pumping station be relocated elsewhere, the installation costs would be higher.

The annual operating costs of the Maunawili Valley-Waimanalo Lagoon system has been estimated at $25,036, which is almost the same as the estimated annual operating cost of the Kawainui Swamp, viz, $24,892. These costs have been based on assumed annual charges for the purchase of water. Any material changes in these assumed purchase prices would be reflected in the estimated annual operating costs. If the Territory were to acquire the Maunawili Valley water rights and flume system by eminent domain proceedings and not charge the Authority for water, the annual operating costs of the Maunawili Valley-Waimanalo Lagoon system would be materially reduced. If, on the other hand, the Territorial Legislature were to grant the Authority the powers of eminent domain to acquire the Maunawili Valley water rights and flume system, and if the Authority included appropriate charges for this acquisition

in its annual operating costs, then these costs would not be materially changed from the estimated costs contained in this report.

The principle has been advanced that the Maunawili Valley water is of better quality than the Swamp water and, therefore, should be reserved or developed for domestic purposes. The need for additional domestic water in the Waimanalo-Kailua area is recognized. However, the surface and ground water flowing into Kawainui Swamp could be collected for domestic use by wells and/or storage reservoirs before entering the Swamp and after filtration, it could be economically utilized. It is not believed, however, that this method of developing the Swamp influent water could be adopted economically for irrigation purposes.

THE CONCLUSIONS OF THIS REPORT ARE:

(1) That either the Maunawili Valley-Waimanalo Lagoon system or the Kawainui Swamp system (utilizing the Swamp for storage) will be adequate as the primary source of water for irrigating the Waimanalo Farm Lots;

(2) That there is no significant difference between the annual operating costs of the two primary sources of water supply based on assumed prices to be paid for the source water as shown in this report;

(3) That if the Territory acquires the Maunawili water rights and flume system and does not charge the Authority for this water, the annual operating costs favor the Maunawili Valley-Waimanalo Lagoon system;

(4) That the utilization of the Maunawili Valley-Waimanalo Lagoon system will depend upon either:

(a) A successful negotiation with the owners of the Maunawili Valley water rights and flume system for a 25-year lease at a favorable cost to the Authority; or

(b) The acquisition through eminent domain proceedings of the water rights and flume system in Maunawili Valley.

(5) That the utilization of the Kawainui Swamp system will depend upon the following:

(a) Utilization of the Swamp as a storage reservoir of sufficient capacity to meet the irrigation needs at an economical cost to the Authority;

(b) The right to install pumps and utilize the existing site of the former pumping station in the Swamp;

(c) An agreement that no developments will be undertaken in Maunawili Valley or in the Kawainui Swamp that will divert or reduce the present flow of surface and ground water into the Swamp;

(d) The successful negotiation with the owners of the Swamp for the purchase of the Swamp water, necessary rights of way and the use of the Kawainui-Waimanalo tunnel on a 25-year basis at an economic cost to the Authority;

(e) That any mosquito or obnoxious odor problems created by the use of the Swamp as a storage reservoir will not be the responsibility of the Authority or, if so, that the control of these problems can be accomplished at an economical cost to the Authority without endangering the water supply for irrigation purposes.

ACREAGES AND WATER DELIVERIES - WAIMANALO IRRIGATION SYSTEM, OAHU
January 1954 to October 1956

(1) Year	Month	(2) ACREAGES Assessed Area (acres)	(3) Irrigated Area (acres)	(4) Irrigated Area Percent of Assessed Area	(5) WATER DELIVERIES TO FARM TURNOUTS Total (1000 gallons)	(6) Percent of Annual Total	(7) Per Assessed Acre (1000 gallons)	(8) Per Assessed Acre (acre-inches)	(9) Per Irrigated Acre (1000 gallons)	(10) Per Irrigated Acre (acre-inches)	(11) RAINFALL(1) Monthly Total (inches)	(12) Station Mean/Month (inches)	(13) Monthly Rainfall as a Percent of Mean
1954	Jan.	808	-	-	2,958	2.4	3.7	0.14	-	-	3.58	6.05	59
	Feb.	813	-	-	2,572	2.1	3.2	.12	-	-	6.50	5.12	127
	Mar.	807	-	-	2,221	1.8	2.8	.10	-	-	5.17	5.32	97
	Apr.	842	-	-	14,103	11.4	16.7	.62	-	-	3.86	4.01	96
	May	862	-	-	6,132	4.9	7.1	.26	-	-	2.01	2.49	81
	June	868	-	-	18,952	15.3	21.8	.80	-	-	0.79	1.40	56
	July	875	-	-	14,539	11.7	16.6	.61	-	-	3.97	1.39	286
	Aug.	853	-	-	14,790	11.9	17.3	.64	-	-	1.08	1.71	63
	Sept.	859	-	-	22,835	18.4	26.6	.98	-	-	0.69	1.87	37
	Oct.	859	-	-	15,493	12.5	18.0	.66	-	-	2.48	3.27	76
	Nov.	837	-	-	9,265	7.5	11.1	.41	-	-	16.33	4.15	393
	Dec.	843	-	-	143	0.12	0.17	.006	-	-	4.85	6.28	77
Total		-	-	-	124,003	100.0	-	-	-	-	51.31	43.06	119
Monthly Mean		844	-	-	10,334	8.3	12.2	0.45	-	-	4.28	3.59	119
Monthly Minimum		807	-	-	143	0.12	0.17	.006	-	-	0.69	1.39	37
Monthly Maximum		875	-	-	22,835	18.4	26.6	.98	-	-	16.33	6.28	393
1955	Jan.	834	-	-	3,185	2.1	3.8	0.14	-	-	3.90	6.05	64
	Feb.	839	-	-	341	0.22	0.41	.015	-	-	17.83	5.12	348
	Mar.	834	244	29	1,996	1.3	2.4	.09	8.2	0.30	6.26	5.32	118
	Apr.	836	303	36	12,004	7.8	14.4	.53	39.6	1.46	0.72	4.01	18
	May	834	355	43	19,669	12.8	23.6	.87	55.4	2.06	0.83	2.49	33
	June	838	380	45	24,836	16.2	29.6	1.09	65.4	2.40	0.35	1.40	25
	July	834	370	44	28,398	18.4	34.1	1.25	76.8	2.73	0.57	1.39	41
	Aug.	814	334	41	21,808	14.2	26.8	.99	65.3	2.40	1.88	1.71	110
	Sept.	794	291	37	17,590	11.5	22.2	.82	60.4	2.22	1.73	1.87	93
	Oct.	757	286	38	13,692	8.9	18.1	.67	47.9	1.76	1.14	3.27	35
	Nov.	749	286	38	6,604	4.3	8.8	.32	23.1	0.85	5.25	4.15	127
	Dec.	709	273	39	3,473	2.3	4.9	.18	12.7	0.47	18.86	6.28	300
Total		-	-	-	153,596	100.0	-	-	-	-	59.32	43.06	138
Monthly Mean		806	312	39	12,800	8.3	15.9	0.59	45.5	1.67	4.94	3.59	138
Monthly Minimum		709	244	29	341	0.22	0.41	0.015	8.2	0.30	0.35	1.39	18
Monthly Maximum		839	380	45	28,398	18.4	34.1	1.25	76.8	2.73	18.86	6.28	348

ACREAGES AND WATER DELIVERIES - WAIMANALO IRRIGATION SYSTEM, OAHU (Cont'd)
January 1954 to October 1956

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
		ACREAGES			WATER DELIVERIES TO FARM TURNOUTS						RAINFALL(1)		
Year	Month	Assessed Area (acres)	Irrigated Area (acres)	Irrigated Area Percent of Assessed Area	Total (1000 gallons)	Percent of Annual Total	Per Assessed Acre (1000 gallons)	Per Assessed Acre (acre-inches)	Per Irrigated Acre (1000 gallons)	Per Irrigated Acre (acre-inches)	Monthly Total (inches)	Station Mean/Month (inches)	Monthly Rainfall as a Percent of Mean
1956	Jan.	764	205	27	302	0.30	0.40	0.015	1.5	0.055	5.93	6.05	98
	Feb.	756	199	26	559	0.56	0.74	.027	2.8	0.10	3.60	5.12	70
	Mar.	775	226	29	3,761	3.8	4.9	.18	16.6	0.61	1.15	5.32	22
	Apr.	772	249	32	6,844	6.9	8.9	.33	27.5	1.01	2.62	4.01	65
	May	782	261	33	13,371	13.5	17.1	.63	51.2	1.89	1.55	2.49	62
	June	772	280	36	14,903	15.0	19.3	.71	53.2	1.96	1.24	1.40	89
	July	759	255	34	19,928	20.1	26.3	.97	78.1	2.88	0.87	1.39	63
	Aug.	781	251	32	19,989	20.2	25.6	.94	79.6	2.94	1.80	1.71	105
	Sept.	826	228	28	15,629	15.8	18.9	.69	68.5	2.53	1.76	1.87	94
	Oct.	846	258	31	3,909	3.9	4.6	.14	15.2	0.56	8.76	3.27	268
Total		-	-	-	99,195	100.1	-	-	-	-	29.28	32.63	90
Monthly Mean		783	241	31	9,920	10.0	12.7	0.47	39.4	1.45	2.93	3.26	90
Monthly Minimum		756	199	26	302	0.30	0.40	0.015	1.5	0.055	0.87	1.39	22
Monthly Maximum		846	280	36	19,989	20.2	26.3	0.97	79.6	2.94	8.76	6.05	268
January 1954 to October 1956													
Total		-	-	-	376,794	100.0	-	-	-	-	139.91	118.75	118
Monthly Mean		813	277	35	11,082	8.8	13.6	0.50	42.5	1.56	4.12	3.49	118
Monthly Minimum		709	199	26	143	0.12	0.17	0.006	1.5	0.055	0.35	1.39	18
Monthly Maximum		875	380	45	28,398	20.2	34.1	1.25	79.6	2.94	18.86	6.28	393

(1) Waimanalo Office Rainfall Station. Mean obtained from 57 years of record.
Rainfall for 1954 from University of Hawaii Experimental Farm Station.

ACREAGES AND WATER DELIVERIES, FOURTEEN REPRESENTATIVE FARMS(1) - WAIMANALO
For Twelve-month Period - November 1955 to October 1956

(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
			IRRIGABLE AREA		IRRIGATED AREA			WATER DELIVERIES TO FARM TURNOUTS						RAINFALL(2)		
										Per Assessed Acre		Per Irrigated Acre				
Year	Month	Assessed Area (Acres)	Acres	Percent of Assessed Area	Acres	Percent of Assessed Area	Percent of Irrigable Area	Total to All Farms (1000 gals.)	Percent of Yearly Total	(1000 gallons)	(Acre-inches)	(1000 gallons)	(Acre-inches)	Monthly Total (Inches)	Station Mean/Month (Inches)	Monthly Rainfall as a Percent of the Mean
1955	Nov.	132	122	92	72	55	59	1,539	5.6	11.7	0.43	21.4	0.79	5.25	4.15	127
"	Dec.	132	122	92	69	53	57	805	2.9	6.1	0.22	11.7	0.43	18.86	6.28	300
1956	Jan.	132	122	92	55	42	45	57	0.21	0.43	0.016	1.0	0.037	5.93	6.05	98
"	Feb.	132	122	92	57	43	47	195	0.71	1.5	0.055	3.4	0.13	3.60	5.12	70
"	Mar.	132	122	92	65	49	53	1,499	5.4	11.4	0.42	23.1	0.85	1.15	5.32	22
"	Apr.	132	122	92	62	47	51	1,893	6.9	14.3	0.53	30.5	1.12	2.62	4.01	65
"	May	132	122	92	68	52	56	3,549	12.9	26.9	0.99	52.2	1.92	1.55	2.49	62
"	June	132	122	92	72	55	59	3,817	13.9	28.9	1.06	53.0	1.95	1.24	1.40	89
"	July	132	122	92	64	49	53	4,735	17.2	35.9	1.32	74.0	2.73	0.87	1.39	63
"	Aug.	132	122	92	67	51	55	4,896	17.8	37.1	1.37	73.1	2.69	1.80	1.71	105
"	Sept.	132	122	92	65	49	53	3,607	13.1	27.3	1.01	55.5	2.04	1.76	1.87	94
"	Oct.	132	122	92	67	51	55	927	3.4	7.0	0.26	13.8	0.51	8.76	3.27	268
Total		---	---	---	---	---	---	27,519	---	208.5	7.68	412.7	15.20	53.39	43.06	124
Mean		132	122	92	65	50	54	2,293	8.3	17.4	0.64	34.4	1.27	4.45	3.59	124
Minimum		132	122	92	55	42	45	57	0.21	0.43	0.016	1.0	0.037	0.87	1.39	22
Maximum		132	122	92	72	55	59	4,896	17.8	37.1	1.37	74.0	2.73	18.86	6.28	300

(1) Fourteen farms selected on the basis of their being typical farms having variable soil and rainfall conditions, diversification of crops and representing different farming and irrigation practices.

(2) Waimanalo Office Rainfall Station. Mean obtained from 57 years of record.

EXHIBIT II

RAINFALL DATA
Waimanalo Office, Oahu
Lat. 21° 21' N
Long. 157° 44' W
Elevation 20'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1894				1.10	0.11	1.12	0.78	0.81	1.01	1.73	9.88	2.12	18.66
1895	3.36	2.58	0.93	0.90	4.27	0.88	1.15	2.07	4.28	5.69	6.61	16.33	49.05
1896	5.33	1.76	2.65	2.70	0.92	1.15	0.94	2.08	0.33	3.41	11.12	9.13	41.52
1897	2.48	0.61	1.44	0.31	1.67	0.73	1.12	1.07	2.96	3.15	3.69	3.13	22.36
1898	1.87	11.20	12.35	1.68	1.26	2.74	1.19	0.63	0.37	1.83	0.45	5.67	41.24
1899	1.18	7.17	8.45	1.91	10.09	0.39	0.75	0.87	0.68	2.55	0.48	4.00	38.52
1900	2.20	2.38	2.54	3.68	1.48	0.79	2.35	1.33	0.68	5.27	19.56	2.42	44.68
1901	4.91	15.87	5.17	2.49	5.30	1.57	1.20	0.57	0.85	2.14	3.80	15.39	59.26
1902	0.74	1.43	17.06	1.52	0.68	7.45	1.68	1.10	1.53	2.69	9.77	13.02	58.67
1903	4.00	2.84	0.80	3.17	0.99	1.56	2.37	1.16	3.71	1.96	3.76	1.99	28.31
1904	2.82	41.03	16.35	2.03	0.44	0.66	1.51	4.78	4.08	1.38	6.37	9.30	90.75
1905	3.84	0.42	3.41	3.41	2.70	1.10	2.99	2.74	2.33	0.88	3.86	5.42	33.10
1906	3.79	0.55	7.90	2.15	1.17	0.96	1.52	1.40	1.21	1.76	5.76	15.81	43.98
1907	22.25	7.07	2.83	2.37	9.98	1.38	1.46	2.95	1.75	1.33	2.50	4.38	60.25
1908	1.55	6.81	15.34	0.63	1.94	0.74	0.76	1.84	1.31	1.28	1.89	1.59	35.68
1909	4.76	3.01	4.95	6.56	1.84	1.22	1.65	0.60	0.68	3.38	1.01	7.53	37.19
1910	2.90	2.27	1.45	1.53	2.05	2.01	1.14	4.49	7.34	2.83	2.46	5.63	36.10
1911	3.59	13.84	5.05	1.09	7.44	0.71	0.65	1.19	2.32	1.81	0.83	2.67	41.19
1912	1.05	2.88	1.46	1.59	0.61	0.64	1.59	2.77	0.64	1.57	2.80	3.75	21.35
1913	3.46	5.58	3.82	1.19	6.13	5.86	0.84	2.59	1.16	2.04	2.26	3.12	38.05
1914	4.25	1.75	11.30	9.36	3.94	0.81	0.52	0.45	2.73	0.93	2.36	7.07	45.47

RAINFALL DATA (Cont'd)
Waimanalo Office, Oahu
Lat. 21° 21' N
Long. 157° 44' W
Elevation 20'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1915	0.80	1.43	1.29	10.73	1.74	1.13	3.40	1.11	3.43	1.63	8.03	12.03	46.75
1916	28.21	2.68	5.39	3.17	3.49	0.48	1.57	1.49	0.87	1.32	1.69	5.44	55.80
1917	11.21	4.32	15.40	6.15	3.05	0.69	0.28	1.61	1.18	5.50	5.19	8.61	63.19
1918	8.75	6.50	7.95	18.89	1.78	1.68	0.82	3.62	0	1.76	11.72	3.43	66.90
1919	1.23	0.67	2.51	2.83	1.14	3.28	1.48	1.33	1.73	2.23	1.97	4.50	24.90
1920	4.74	0.94	5.67	2.30	1.18	1.45	1.46	1.25	0.55	2.18	3.22	11.58	36.52
1921	11.66	1.89	2.02	1.64	0.92	0.54	0.85	0.84	0.75	4.84	2.48	9.28	37.71
1922	5.18	1.55	1.26	3.46	0.81	1.50	0.81	0.97	3.16	2.97	3.11	0.97	25.75
1923	23.96	8.52	9.75	11.47	0.56	0.46	0.47	1.62	1.96	2.88	1.10	10.40	73.15
1924	0.22	3.94	3.12	17.96	2.63	0.84	1.95	1.06	1.08	2.78	2.15	6.24	43.97
1925	1.90	2.06	4.75	2.20	0.90	0.90	1.51	0.38	2.13	3.12	3.68	5.92	29.45
1926	2.78	0.88	1.19	2.82	0.56	5.05	0.74	1.25	0.80	5.23	0.69	1.95	23.94
1927	5.89	4.17	12.37	13.60	4.56	0.74	1.46	0.96	2.23	0.60	7.95	15.11	69.64
1928	0.60	2.62	1.36	7.43	1.55	0.77	1.49	1.42	0.84	1.92	2.92	1.33	24.25
1929	7.00	2.47	0.51	0.75	2.24	0.34	0.81	1.03	0.37	2.09	9.59	8.12	35.32
1930	10.81	3.94	6.23	1.26	0.41	0.96	0.87	5.65	7.99	4.56	4.26	1.34	48.28
1931	0.88	0.41	3.51	1.88	2.51	0.38	2.62	2.22	2.73	5.34	1.51	5.00	28.99
1932	3.30	14.68	1.52	2.83	1.22	0.37	1.47	1.38	1.49	1.83	4.36	3.47	37.92
1933	2.64	7.75	12.35	0.77	0.83	0.62	0.93	0.63	0.73	1.11	1.51	8.04	37.91
1934	4.00	3.78	2.13	2.30	1.73	2.16	0.75	3.53	2.50	4.91	2.69	2.21	32.69
1935	9.18	2.82	5.14	0.70	0.46	2.58	3.42	1.37	1.66	9.05	7.00	3.96	47.34

RAINFALL DATA (Cont'd)
Waimanalo Office, Oahu
Lat. 21° 21' N
Long. 157° 44' W
Elevation 20'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1936	7.76	2.16	3.27	5.53	0.54	2.32	1.16	1.58	1.53	12.31	3.87	1.47	43.50
1937	8.78	8.99	8.49	(4.60)*	4.30	0.67	4.26	1.62	1.90	6.47	1.49	13.56	65.13
1938	2.53	8.49	9.19	3.69	10.53	0.60	3.01	6.64	0.52	4.20	1.67	10.41	61.48
1939	3.39	4.08	3.69	11.14	1.82	1.64	0.79	0.73	3.81	15.30	2.84	2.11	51.34
1940	5.62	2.52	5.02	2.70	7.11	0.63	0.86	2.17	2.02	3.47	5.14	2.38	39.64
1941	2.93	1.52	2.42	0.71	0.65	2.62	1.17	0.95	1.95	8.78	1.05	1.42	26.17
1942	1.86	6.81	6.93	2.46	1.06	0.93	1.88	1.31	1.77	7.93	4.01	7.70	44.65
1943	25.49	2.60	3.88	2.02	8.39	0.60	1.21	2.26	0.76	1.77	0.59	2.86	52.43
1944	0.53	8.54	8.38	1.08	0.29	1.86	0.76	0.50	0.38	1.91	4.46	2.34	31.03
1945	0.81	2.69	0.54	13.79	0.87	0.47	0.35	1.58	1.83	0.79	1.04	7.36	32.12
1946	7.00	2.57	1.02	0.77	0.32	1.45	1.78	0.59	0.34	2.16	3.95	4.98	26.93
1947	3.47	0.76	8.53	4.11	2.70	1.29	0.98	0.71	6.98	0.70	3.69	3.16	37.08
1948	12.17	5.20	1.28	(6.60)*	(5.25)*	(6.8)*	(2.18)*	(1.97)*	1.37	0.70	7.39	3.28	54.19
1949	17.97	6.24	1.76	1.22	0.64	1.82	1.30	0.68	0.83	1.06	1.94	2.94	38.40
1950	15.18	1.89	1.86	7.94	2.47	1.00	1.61	2.32	0.86	3.67	(9.78)*	10.77	59.35
1951	. . . . . No Record												
1952	. . . . . No Record												
1953	. . . . . No Record												
1954	. . . . . No Record												
1955	3.90	17.83	6.26	0.72	0.83	0.35	0.57	1.88	1.73	1.14	5.25	18.86	59.32
Mean	6.05	5.12	5.32	4.01	2.49	1.40	1.39	1.71	1.87	3.27	4.15	6.28	43.06

( )* Estimated figures not included in means.

Source: U. S. Weather Bureau

MAUNAWILI DITCH - MONTHLY DISCHARGE IN MILLIONS OF GALLONS
AT ANIANI NUI RIDGE, OAHU
1927-1941

(Monthly totals shown only for those months in which the records indicate that the total available flow of the Ditch was utilized.)

Month \ Year	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941
Jan.	—	—	—	—	94	—	—	—	—	—	—	—	—	—	—
Feb.	—	—	—	—	70	—	—	—	—	—	—	—	—	—	—
Mar.	—	87	66	—	74	—	—	75	—	—	—	—	—	—	—
Apr.	—	—	86	—	—	113	101	78	91*	—	—	—	—	—	101
May	—	—	75	100	—	—	87	103	97	—	—	—	—	—	86
June	103	91	65	82	81	102	73	98	96	103	101*	125	108	119	76
July	87	90	57	75	71	89	68	87	80*	88	100	119	102	97	77
Aug.	76	87	57	71*	100	102	67	80	80	90	102	—	95	96	78
Sept.	70	81	52	—	—	92	64	—	80	96	95	110	—	100	88
Oct.	70	74	55	—	—	85	60	—	—	—	—	—	—	—	—
Nov.	—	—	—	—	—	—	53	—	—	—	—	—	—	—	—
Dec.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Adjusted for one to three days during the month when the ditch flow was diverted in Maunawili Valley.

Source: Waimanalo Agricultural Development Company's records.
Austin and Towill's Maunawili Ditch record.

EXHIBIT V

RAINFALL DATA
Maunawili Ranch, Oahu
Lat. 21° 22' N
Long. 157° 46' W
Elevation 250'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1895	4.08	4.07	1.64	2.93	4.94	4.27	4.05	7.33	9.45	9.87	8.32	17.65	78.60
1896	4.97	3.38	7.34	4.92	3.73	2.94	2.70	7.63	1.11	5.54	7.76	10.83	62.85
1897	4.68	1.75	2.80	0.79	4.06	2.46	5.04	3.35	10.82	10.38	4.70	4.08	54.91
1898	4.93	10.72	15.69	2.32	2.92	4.51	3.59	3.31	0.94	3.74	1.93	4.23	58.83
1899	2.42	4.35	14.66	4.21	4.90	0.92	2.13	2.62	2.47	4.35	1.40	2.90	47.33
1900	1.96	3.85	3.28	12.19	3.71	2.80	5.32	8.85	2.40	9.68	19.60	5.56	79.20
1901	5.70	17.13	8.52	8.99	11.59	2.59	4.02	2.32	1.87	4.17	6.18	17.31	90.39
1902	1.58	2.05	15.31	18.57	4.91	8.76	6.13	3.01	6.74	5.42	11.02	19.45	102.95
1903	6.73	5.02	1.95	8.26	5.10	6.91	6.92	6.00	6.63	3.19	6.90	4.81	68.42
1904	5.95	44.65	19.97	4.59	2.30	2.69	3.47	13.57	8.94	2.45	8.17	14.38	131.13
1905	4.58	1.09	3.86	9.24	8.73	3.31	5.52	7.29	7.14	3.32	9.56	9.78	73.42
1906	4.34	2.31	5.91	4.38	5.16	2.56	3.52	4.06	3.94	4.47	11.34	16.61	68.60
1907	25.74	14.83	5.73	5.17	16.78	6.87	3.72	10.45	8.83	5.85	5.02	6.39	115.38
1908	2.29	4.14	17.27	2.69	6.05	3.15	2.48	5.84	5.00	4.43	3.86	3.93	61.13
1909	4.30	5.42	6.85	7.97	5.31	5.25	6.12	2.26	2.05	6.72	2.44	10.94	65.63
1910	4.58	5.98	4.62	4.20	6.51	5.50	2.73	10.24	10.22	4.45	5.87	10.79	75.69
1911	7.23	17.91	7.95	3.11	11.64	4.27	4.06	7.16	6.37	4.48	3.66	7.50	85.34
1912	2.76	6.50	6.40	7.11	3.35	2.84	3.54	5.65	2.32	5.34	4.39	6.68	56.88
1913	7.83	7.79	6.87	4.41	7.95	8.29	1.29	6.51	4.37	3.71	8.57	8.77	76.36
1914	6.68	2.80	11.54	17.81	11.88	6.20	7.51	5.22	20.12	2.98	7.74	8.97	109.45
1915	2.30	5.05	2.78	16.54	4.03	5.10	8.34	2.18	6.57	5.90	12.27	15.49	86.55

RAINFALL DATA (Cont'd)
Maunawili Ranch, Oahu
Lat. 21° 22' N
Long. 157° 46' W
Elevation 250'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1916	30.07	4.63	8.46	5.83	8.88	3.20	4.60	5.02	3.91	3.57	5.23	10.08	93.48
1917	10.78	5.72	18.79	9.69	5.34	2.66	2.57	3.38	5.68	4.87	7.70	8.35	85.53
1918	14.91	8.20	21.82	25.15	8.94	4.64	5.52	8.80	1.55	3.80	10.34	8.06	121.73
1919	3.41	2.10	5.50	9.04	3.56	5.74	6.37	3.91	4.53	10.51	4.06	4.17	62.90
1920	5.93	1.66	13.15	4.19	2.51	5.59	4.14	4.74	2.47	5.12	7.28	15.70	72.48
1921	35.74	3.12	3.60	4.61	6.83	2.70	5.22	3.13	2.42	9.54	5.41	16.35	98.67
1922	7.85	5.66	3.57	5.98	4.58	3.89	3.94	5.19	7.31	8.55	7.23	2.59	66.34
1923	31.56	15.23	9.70	13.72	1.34	1.91	2.56	4.78	5.74	7.38	3.35	20.66	117.93
1924	1.37	6.75	3.27	22.12	6.82	2.90	4.15	3.86	2.38	6.23	5.70	8.03	73.58
1925	5.39	5.59	7.79	8.37	4.72	4.52	4.96	3.49	5.75	5.92	9.58	7.68	73.76
1926	5.06	2.86	3.52	4.95	3.08	8.72	3.06	6.79	3.96	11.10	3.43	5.93	62.46
1927	7.96	7.45	17.19	22.93	14.35	3.03	4.61	5.00	5.35	3.48	25.57	23.71	140.63
1928	3.35	4.30	2.72	12.30	4.74	3.84	6.31	5.83	3.27	4.25	7.05	4.45	62.41
1929	8.31	4.97	5.30	4.04	4.12	2.65	3.21	4.89	2.49	4.78	11.77	18.83	75.36
1930	14.45	7.29	9.40	5.90	1.84	4.36	3.74	6.20	14.82	8.09	11.68	5.05	92.82
1931	3.27	2.33	4.54	3.37	7.69	1.98	5.86	9.41	8.51	10.03	9.42	8.12	74.53
1932	9.65	23.48	3.76	7.34	11.26	2.99	5.89	8.53	3.92	3.93	7.00	8.36	96.11
1933	5.30	12.08	15.61	2.86	3.56	3.69	4.61	2.78	2.26	2.00	2.76	12.57	70.08
1934	9.14	7.22	3.64	6.59	7.66	4.81	4.66	5.57	9.71	8.47	7.94	6.65	82.06
1935	13.93	7.23	8.68	2.72	6.27	6.58	6.02	5.13	5.80	13.26	10.71	5.00	91.33
1936	13.62	2.87	8.24	11.85	5.85	5.49	5.70	6.41	8.99	16.16	6.34	4.29	95.81

RAINFALL DATA (Cont'd)
Maunawili Ranch, Oahu
Lat. 21° 22' N
Long. 157° 46' W
Elevation 250'

Units in Inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1937	13.43	10.17	10.47	8.86	11.29	2.10	8.34	5.10	5.01	7.70	5.76	15.24	103.47
1938	7.15	7.14	13.26	7.87	17.05	5.78	6.43	10.56	2.81	8.44	3.76	9.04	99.29
1939	8.84	5.68	10.22	15.22	4.78	6.50	3.44	4.48	7.86	17.42	6.60	5.34	96.38
1940	7.69	5.69	5.80	7.16	26.10	3.60	2.98	7.75	4.28	6.69	7.41	4.88	90.03
1941	4.29	2.90	7.30	5.38	3.30	6.01	4.74	5.93	6.42	25.57	2.54	5.28	79.66
1942	4.16	13.94	17.20	6.67	3.23	4.87	5.89	8.00	7.70	7.03	13.83	15.17	107.69
1943	19.60	5.06	9.07	5.79	12.93	2.59	3.76	5.52	2.63	5.36	1.12	6.62	80.05
1944	1.70	8.01	13.63	3.15	....No Record....			1.24	1.00	2.21	5.41	3.50	(39.85)*
1945	1.07	3.35	1.70	18.08	2.53	1.61	3.87	4.58	0.67	1.20	2.61	6.10	47.37
1946	6.51	7.40	1.54	2.69	0.93	1.56	2.80	0.43	0.34	2.25	3.87	2.94	33.26
1947	2.06	1.72	12.05	3.39	2.26	1.30	0.50	1.30	8.15	0.60	3.50	1.40	38.23
1948	8.34	9.94	3.02	8.22	1.74	1.29	2.26	2.79	3.58	0.77	7.04	3.20	52.19
1949	20.33	7.20	1.39	0.63	1.22	3.33	1.32	1.72	0.86	0.90	2.13	4.00	45.03
1950	15.97	4.82	1.55	7.56	3.25	3.65	0.59	4.24	2.13	2.61	7.93	14.01	68.31
1951	12.43	5.28	31.14	3.72	1.82	1.25	1.50	1.91	2.02	9.57	1.70	7.05	79.39
1952	4.63	6.79	1.91	1.88	1.64	0.14	0.45	0.51	0.16	0.53	3.26	5.26	27.16
1953	2.76	..... No Record											(2.76)*
1954	....	13.74	6.18	6.72	5.85	3.68	17.55	7.01	3.35	6.32	18.40	10.46	(99.26)*
1955	5.69	28.00	9.35	2.61	2.29	2.11	3.21	7.45	5.97	2.78	7.84	21.25	98.55
1956	13.05	7.10	5.58	8.92	6.36	6.00	5.72	6.20	5.85	7.71			
Mean	8.53	7.63	8.39	7.68	6.13	3.92	4.42	5.32	5.08	6.18	7.08	9.21	79.57

( )* incomplete total

Source: Kaneohe Ranch Co.
Hawaiian Sugar Planters' Assn.

STREAM FLOW MEASUREMENTS

A. COMBINED MINIMUM DISCHARGE OF ALL STREAMS
IN MILLION GALLONS PER DAY
For Months of June through September
Maunawili Valley, Oahu

		Kahanaiki** Stream	Pohakea Stream	Kamakalepo Stream	Kaimi Stream	Makawao Stream	Total All Streams	Maunawili (Makawao) Ditch	Total All Streams Including Maunawili Ditch	Rainfall Maunawili Ranch Station	Long Term Mean Rainfall	Percent of Mean Rainfall
1913	June	0.19	0.17	1.10	0.97	1.5	3.93	1.49	5.42	8.29	3.92	211
	July	0.15	0.1	0.85	0.8	1.1	3.00	1.2	4.20	1.29	4.42	29
	Aug.	0.16	0.1	0.85	0.8	1.1	3.01	1.4	4.41	6.51	5.32	122
	Sept.	0.09	0.1	0.7	0.8	1.1	2.79	1.0	3.79	4.37	5.07	86
	Mean	0.15	0.12	0.88	0.84	1.2	3.19	1.27	4.46	5.12	4.68	109
1914	June	0.70	0.2*	2.1	1.6	2.3	6.90	1.1	8.00	6.20	3.92	158
	July	0.25	0.2*	1.6	1.3	2.0	5.35	2.2	7.55	7.51	4.42	170
	Aug.	0.25	0.2*	1.6	1.3	2.0	5.35	2.2	7.55	5.22	5.32	98
	Sept.	0.35	0.3*	1.6	1.6	1.6	5.45	1.8	7.25	20.12	5.07	397
	Mean	0.39	0.2*	1.73	1.45	1.97	5.76	1.83	7.59	9.76	4.68	209
1915	June	0.4	0.1*	0.9	1.0	1.6	4.00	2.2	6.20	5.10	3.92	130
	July	0.5	0.1*	0.9	1.2	1.3	4.00	2.2	6.20	8.34	4.42	189
	Aug.	0.3	0.1*	0.9	1.0	1.0	3.30	2.2	5.50	2.18	5.32	41
	Sept.	0.3	0.1*	0.9	0.7	1.0	3.00	1.8	4.80	6.57	5.07	130
	Mean	0.38	0.1*	0.9	0.98	1.23	3.58	2.1	5.68	5.55	4.68	119
1916	June	0.5	0.1*	0.9	1.2	1.4	4.10	1.1*	5.20	3.20	3.92	82
Mean		0.32	0.14	1.15	1.10	1.46	4.17	1.68	5.85	6.53	4.62	141

* Estimated by correlation with flow of Kamakalepo Stream.
** Includes estimated diversions for irrigation ranging from 1.3 to 5.9 million gallons per month.

Source: U. S. Geological Survey

STREAM FLOW MEASUREMENTS

B. COMBINED MEAN DISCHARGE OF ALL STREAMS
IN MILLION GALLONS PER DAY
For Months of June through September
Maunawili Valley, Oahu

		Kahanaiki** Stream	Pohakea Stream	Kamakalepo Stream	Kaimi Stream	Makawao Stream	Total All Streams	Maunawili (Makawao) Ditch	Total All Streams Including Maunawili Ditch	Rainfall Maunawili Ranch Station	Long Term Mean Rainfall	Percent of Mean Rainfall
1913	June	1.2	0.30	2.55	2.16	2.55	8.76	2.04	10.80	8.29	3.92	211
	July	0.28	0.14	1.13	1.04	1.38	3.97	1.57	5.54	1.29	4.42	29
	Aug.	0.39	0.12	1.08	1.04	1.35	3.98	1.66	5.64	6.51	5.32	122
	Sept.	0.48	0.14	1.06	1.09	1.16	3.93	1.28	5.21	4.37	5.07	86
	Mean	0.57	0.18	1.46	1.33	1.61	5.16	1.64	6.80	5.12	4.68	109
1914	June	0.89	0.27*	2.54	2.20	3.19	9.09	2.56	11.65	6.20	3.92	158
	July	0.71	0.26*	2.28	1.90	2.24	7.39	2.45	9.84	7.51	4.42	170
	Aug.	0.57	0.25*	2.07	1.80	2.04	6.73	2.45	9.18	5.22	5.32	98
	Sept.	3.69	0.96*	10.3	7.11	9.74	31.80	2.35	34.15	20.12	5.07	397
	Mean	1.47	0.44*	4.30	3.25	4.30	13.76	2.45	16.21	9.76	4.68	209
1915	June	0.49	0.18*	0.98	1.20	1.72	4.57	2.57	7.14	5.10	3.92	130
	July	0.60	0.20*	1.57	1.34	1.78	5.49	2.39	7.88	8.34	4.42	189
	Aug.	0.46	0.19*	1.33	1.31	1.36	4.65	2.20	6.85	2.18	5.32	41
	Sept.	0.43	0.19*	1.20	1.26	1.27	4.35	2.16	6.51	6.57	5.07	130
	Mean	0.50	0.19*	1.27	1.28	1.53	4.77	2.33	7.10	5.55	4.68	119
1916	June	0.50	0.19*	1.20	1.31	1.77	4.97	2.6*	7.57	3.20	3.92	82
Mean		0.82	0.26	2.25	1.90	2.43	7.66	2.18	9.84	6.53	4.62	141

* Estimated by correlation with flow of Kamakalepo Stream.
** Includes estimated diversions for irrigation ranging from 1.3 to 5.9 million gallons per month.

Source: U. S. Geological Survey

EXHIBIT VIII

1956 STREAM FLOW MEASUREMENTS
MAUNAWILI VALLEY
OAHU

Station No.	Location	DISCHARGE IN MILLION GALLONS PER DAY					
		Sept. 5	Oct. 3	Nov. 14	Mean	Aug. 8	Sept. 28
2	Makawao Stream 20 to 35 feet above confluence with Maunawili Stream	1.15	1.30	1.32	1.26	-	-
3	Kaimi (Maunawili) Stream 100 feet below old Gov't Rd. 16 feet above Makawao Stream	0.527	0.457	0.525	0.503	-	-
4	Kamakalepo Stream 25 feet below old Gov't Rd.	0.599	0.449	0.905	0.651	-	-
5	Drainage Ditch at Pohakea Stream above old Gov't Rd.	0.0226	0.015	0.016	0.018	-	-
6	Pohakea Stream 80 feet above old Gov't Rd.	0.115	0.099	0.196	0.137	-	-
7	South Branch Kahanaiki Stream 175 feet above confluence with South Branch, 150 feet above old Gov't Rd.	0.191	0.234	0.207	0.211	-	-
8	North Branch Kahanaiki Stream 175 feet above confluence with South Branch	0.140	0.096	0.242	0.159	-	-
10	Kahanaiki Stream 60 feet above old Gov't Rd. 40 feet below confluence of North and South Branches	0.384	0.275	0.406	0.355	-	-
12	Maunawili Stream 75 feet below intake to Wong Leong's Ditch	2.30	2.33	2.92	2.52	-	-
13	Wong Leong's Ditch 100 feet below Maunawili Stream	0.0717	0	0	0.024	-	-
14	Maunawili Stream at Kalanianaole Highway	2.56	2.55	3.41	2.84	3.74	2.55
15	Wong Leong's Ditch at Kalanianaole Highway	0.0717	-	0	0.02	-	-
16	Kahanaiki Stream at Kalanianaole Highway	0.789	0.453	0.976	0.739	1.20	0.67

PUMPAGE DATA
Kawainui Swamp, Oahu
1924 to 1941

Year	Month	Days Either Pump Operated	WATER PUMPAGE (Million Gallons) Total for Month	Daily Mean for Month	Maximum Day	LEVEL OF WATER IN POND (Ft.) Maximum Height	Minimum Height	Height - Last Day of Month	SALINITY (Gr. per gal.) Maximum During Month	RAINFALL (Inches) Kawainui Swamp Pump Total	Maximum Day
1924	Jan.	-	-	-	-	-	-	-	-	-	-
	Feb.	-	-	-	-	-	-	-	-	-	-
	Mar.	-	-	-	-	-	-	-	-	-	-
	Apr.	-	-	-	-	-	-	-	-	-	-
	May	-	-	-	-	-	-	-	-	-	-
	June	20	80.9	2.7	6.2	3.42	2.64	2.64	7.1	0.70	0.25
	July	29	152.9	4.9	7.3	2.65	1.62	1.62	9.1	1.99	0.83
	Aug.	31	186.3	6.0	8.1	1.60	-1.50	-1.50	9.6	1.09	0.31
	Sept.	30	89.6	3.0	5.2	-0.80	-3.50	-3.50	15.4	0.95	0.58
	Oct.	25	69.1	2.2	4.6	-0.60	-3.90	-0.69	18.8	2.95	1.25
	Nov.	11	32.0	1.1	4.3	0.58	-1.06	0.58	17.8	2.27	0.70
	Dec.	7	29.9	1.0	6.1	2.38	0.36	2.38	9.0	7.11	2.81
	Total	153	640.7	-	-	-	-	-	-	17.06	-
1925	Jan.	-	-	-	-	-	-	-	-	-	-
	Feb.	-	-	-	-	-	-	-	-	-	-
	Mar.	5	15.4	0.5	3.9	3.55	3.48	3.60	4.1	4.26	1.25
	Apr.	26	119.7	4.0	6.5	3.90	3.32	3.34	4.8	2.89	0.66
	May	31	133.7	4.3	6.0	3.36	2.71	2.71	5.1	1.74	0.60
	June	30	155.9	5.2	6.5	2.71	1.93	1.93	7.8	1.12	0.14
	July	31	165.0	5.3	7.1	1.89	0.40	0.40	8.2	1.70	0.30
	Aug.	31	130.1	4.2	6.2	0.30	-3.40	-2.95	18.1	0.80	0.28
	Sept.	20	66.2	2.2	6.1	-0.23	-4.90	-0.88	30.1	1.43	0.65
	Oct.	28	124.9	4.0	6.7	-0.80	-4.50	-0.82	21.9	2.28	0.52
	Nov.	3	7.5	0.2	3.8	1.37	-0.72	1.37	7.5	3.63	-
	Dec.	8	14.3	0.5	2.0	1.74	1.37	2.85	5.8	4.52	1.83
	Total	213	932.7	-	-	-	-	-	-	24.37	-
1926	Jan.	-	-	-	-	-	-	3.85	-	2.32	-
	Feb.	-	-	-	-	-	-	3.95	-	1.09	-
	Mar.	28	142.0	4.6	5.9	3.95	3.25	3.25	4.8	1.62	1.06
	Apr.	27	117.0	3.9	5.6	3.25	2.89	2.89	5.5	2.29	1.06
	May	31	179.5	5.8	7.3	2.82	1.70	1.70	7.5	0.63	0.13
	June	10	45.9	1.5	6.7	2.44	1.43	2.40	8.6	4.19	1.00
	July	29	168.5	5.4	6.8	2.35	1.08	1.08	6.5	0.99	0.27
	Aug.	31	191.1	6.2	7.6	1.05	-2.92	-2.45	16.8	1.44	0.50
	Sept.	29	79.9	2.7	4.3	-1.85	-3.67	-2.60	23.6	1.55	0.37
	Oct.	23	50.3	1.6	4.2	1.15	-4.46	1.15	16.1	3.43	1.34
	Nov.	3	7.5	0.2	3.8	1.75	1.15	1.73	-	2.11	1.37
	Dec.	13	36.7	1.2	4.1	1.94	1.65	1.94	5.1	1.84	1.00
	Total	224	1018.4	-	-	-	-	-	-	23.50	-

PUMPAGE DATA (Cont'd)
Kawainui Swamp, Oahu
1924 to 1941

Year	Month	Days Either Pump Operated	WATER PUMPAGE(Million Gallons) Total for Month	Daily Mean for Month	Maximum Day	LEVEL OF WATER IN POND (Ft.) Maximum Height	Minimum Height	Height - Last Day of Month	SALINITY (Gr. per gal.) Maximum During Month	RAINFALL (Inches) Kawainui Swamp Total	Pump Maximum Day
1927	Jan.	6	10.8	0.3	3.2	2.9	2.0	2.9	4.1	3.88	1.7
	Feb.	-	-	-	-	-	-	-	-	5.07	-
	Mar.	-	-	-	-	-	-	-	-	12.84	-
	Apr.	-	-	-	-	-	-	-	-	12.55	-
	May	-	-	-	-	-	-	-	-	4.66	-
	June	23	122.9	4.1	6.4	4.53	4.02	4.02	4.1	1.31	0.44
	July	30	177.4	5.7	7.6	4.01	3.32	3.32	5.8	1.87	0.33
	Aug.	31	208.6	6.7	7.5	3.25	2.33	2.33	6.8	1.37	0.29
	Sept.	30	178.1	5.9	6.9	2.28	1.70	1.84	7.5	4.69	3.00
	Oct.	31	153.2	4.9	6.4	1.85	1.04	1.04	6.5	1.96	0.80
	Nov.	4	16.7	0.6	5.6	4.17	0.94	4.17	6.2	9.22	3.00
	Dec.	-	-	-	-	-	-	-	-	-	-
	Total	155	867.7	-	-	-	-	-	-	59.42	-
1928	Jan.	-	-	-	-	-	-	3.75	-	1.34	-
	Feb.	11	19.3	0.7	2.2	3.97	3.35	3.74	5.5	1.99	1.13
	Mar.	27	124.7	4.0	7.8	3.62	2.15	2.57	5.5	1.35	0.44
	Apr.	11	28.0	0.9	5.0	2.86	2.44	2.65	5.1	5.43	2.50
	May	9	63.8	2.1	7.8	3.08	2.78	2.78	5.8	1.80	0.49
	June	30	225.1	7.5	7.8	2.75	1.34	1.34	6.8	1.16	0.59
	July	30	218.9	7.1	7.8	1.45	-0.09	-0.70	15.7	2.28	0.59
	Aug.	30	172.6	5.6	7.8	0.00	-2.98	-2.82	20.9	1.29	0.38
	Sept.	30	92.4	3.1	4.1	-2.36	-3.65	-2.97	38.7	0.51	0.08
	Oct.	31	67.4	2.2	2.8	-1.49	-3.70	-1.49	23.3	1.51	0.68
	Nov.	3	10.2	0.3	4.1	1.75	-1.56	1.75	7.5	3.35	0.95
	Dec.	8	16.9	0.5	3.4	1.32	-1.32	1.32	5.1	2.26	0.52
	Total	220	1039.3	-	-	-	-	-	-	24.27	-
1929	Jan.	16	72.9	2.4	7.6	1.39	1.18	2.30	4.1	4.94	2.76
	Feb.	3	7.3	0.3	3.9	2.54	2.52	2.82	3.4	3.39	0.79
	Mar.	13	39.6	1.3	4.4	3.18	2.92	2.92	3.4	1.22	0.26
	Apr.	30	192.6	6.4	7.9	2.85	1.82	1.82	5.1	1.04	0.31
	May	30	180.5	5.8	7.8	1.73	0.60	0.60	-	1.33	0.48
	June	29	163.5	5.5	7.9	0.57	-4.35	-2.38	29.1	0.49	0.06
	July	29	60.0	1.9	3.6	-2.58	-3.86	-2.76	43.1	0.82	0.22
	Aug.	30	46.2	1.5	2.5	-2.05	-3.53	-2.66	19.8	0.96	0.26
	Sept.	26	41.2	1.4	2.3	-2.75	-3.42	-2.90	6.5	1.00	0.29
	Oct.	27	43.0	1.4	1.8	-2.55	-3.21	-2.80	-	2.14	0.39
	Nov.	2	3.1	0.1	1.5	-1.52	-2.87	0.34	3.8	7.54	3.06
	Dec.	-	-	-	-	-	-	4.46	-	10.05	-
	Total	235	849.9	-	-	-	-	-	-	34.92	-

PUMPAGE DATA (Cont'd)
Kawainui Swamp, Oahu
1924 to 1941

Year	Month	Days Either Pump Operated	WATER PUMPAGE(Million Gallons) Total for Month	Daily Mean for Month	Maximum Day	LEVEL OF WATER IN POND (Ft.) Maximum Height	Minimum Height	Height Last Day of Month	SALINITY (Gr. per gal.) Maximum During Month	RAINFALL (Inches) Kawainui Swamp Total	Pump Maximum Day
1930	Jan.	-	-	-	-	-	-	4.75	-	12.92	-
	Feb.	-	-	-	-	-	-	5.18	-	4.48	-
	Mar.	-	-	-	-	-	-	5.05	-	4.46	-
	Apr.	3	8.7	0.3	2.9	4.53	4.53	4.53	3.4	1.60	-
	May	30	222.5	7.2	8.0	4.54	3.77	3.77	4.8	0.55	0.16
	June	30	224.9	7.5	7.9	3.74	2.84	2.84	6.8	0.65	0.16
	July	31	206.6	6.7	7.8	2.82	1.79	1.79	7.5	0.82	0.17
	Aug.	29	217.2	7.0	7.8	1.75	0.54	1.14	8.6	3.61	2.11
	Sept.	-	-	-	-	-	-	3.10	-	5.98	-
	Oct.	-	-	-	-	-	-	3.60	-	5.61	-
	Nov.	6	13.7	0.5	2.5	-	-	4.20	3.4	5.58	1.88
	Dec.	-	-	-	-	-	-	3.05	-	1.58	-
	Total	129	893.6	-	-	-	-	-	-	47.84	-
1931	Jan.	30	123.7	4.0	6.0	3.14	2.94	2.94	4.5	0.83	0.24
	Feb.	27	186.7	6.7	7.9	2.94	2.21	2.21	6.8	0.76	0.13
	Mar.	23	129.0	4.2	7.8	2.24	1.65	1.75	5.8	1.52	0.55
	Apr.	10	39.4	1.3	6.1	1.82	1.68	1.77	6.8	1.94	0.84
	May	21	110.8	3.6	7.6	1.75	1.18	1.54	5.5	3.01	0.71
	June	28	158.9	5.3	6.6	1.54	0.04	0.04	-	0.43	0.11
	July	26	169.0	5.5	7.9	0.15	-1.12	-1.12	7.2	1.63	0.38
	Aug.	31	113.5	3.7	6.4	-0.55	-1.69	-0.74	10.9	3.06	0.52
	Sept.	20	76.8	2.6	7.7	0.79	-0.84	0.63	-	3.34	1.16
	Oct.	13	76.2	2.5	7.7	2.74	0.33	2.74	4.5	5.90	1.92
	Nov.	12	31.2	1.0	4.2	2.70	2.30	2.30	-	2.64	1.21
	Dec.	11	18.0	0.6	1.8	2.75	2.16	2.85	-	7.73	5.95
	Total	252	1233.2	-	-	-	-	-	-	32.79	-
1932	Jan.	-	-	-	-	-	-	3.80	-	5.10	-
	Feb.	-	-	-	-	-	-	5.85	-	16.86	-
	Mar.	-	-	-	-	-	-	-	-	2.03	-
	Apr.	24	182.8	-	8.3	3.62	3.41	3.54	8.9	2.00	0.63
	May	21	138.4	4.5	8.1	5.15	3.37	3.37	25.9	1.49	0.90
	June	30	221.0	7.4	7.9	3.36	2.63	2.63	13.7	0.98	0.57
	July	30	214.7	6.9	7.9	2.60	1.81	1.81	14.7	1.47	0.26
	Aug.	29	176.5	5.7	8.0	1.87	1.44	1.44	-	1.71	0.39
	Sept.	30	222.6	7.4	8.0	1.38	0.31	0.31	12.3	1.60	0.80
	Oct.	30	167.2	5.4	8.0	0.29	-1.34	-1.00	19.5	1.55	0.25
	Nov.	12	45.7	1.5	4.1	-	-	-	-	5.56	4.22
	Dec.	-	-	-	-	-	-	-	-	3.35	-
	Total	206	1368.9	-	-	-	-	-	-	43.70	-

PUMPAGE DATA (Cont'd)
Kawainui Swamp, Oahu
1924 to 1941

Year	Month	Days Either Pump Operated	WATER PUMPAGE (Million Gallons) Total for Month	Daily Mean for Month	Maximum Day	LEVEL OF WATER IN POND (Ft.) Maximum Height	Minimum Height	Height - Last Day of Month	SALINITY (Gr. per gal.) Maximum During Month	RAINFALL (Inches) Kawainui Swamp Pump Total	Maximum Day
1933	Jan.	4	15.6	0.5	5.5	2.80	2.79	2.80	-	3.45	1.38
	Feb.	7	44.7	1.6	8.0	3.65	2.85	3.65	29.1	8.47	2.21
	Mar.	4	24.8	0.8	8.0	3.45	3.40	3.43	17.1	12.30	6.98
	Apr.	30	209.3	7.0	8.0	3.42	2.95	2.95	9.9	1.25	0.47
	May	31	220.1	7.1	8.0	2.92	2.11	2.11	11.6	0.93	0.39
	June	30	219.2	7.3	7.6	2.05	0.71	0.71	12.3	1.05	0.26
	July	31	204.0	6.6	7.4	0.69	-1.82	-1.82	15.1	1.48	0.24
	Aug.	31	83.8	2.7	4.3	-1.86	-3.05	-3.00	17.1	1.04	0.41
	Sept.	30	51.8	1.7	2.0	-2.97	-3.40	-3.40	17.8	0.63	0.15
	Oct.	31	36.5	1.2	1.4	-3.25	-3.45	-3.26	-	0.38	0.08
	Nov.	24	36.7	1.2	2.5	-2.20	-3.50	-3.45	23.6	1.23	0.44
	Dec.	21	28.3	0.9	1.7	0.47	-3.46	0.47	18.8	7.77	-
	Total	274	1174.8	-	-	-	-	-	-	39.98	-
1934	Jan.	7	25.5	0.8	6.8	1.39	0.50	1.39	18.5	3.18	1.03
	Feb.	2	1.8	0.1	1.7	2.52	1.48	2.46	-	3.73	1.00
	Mar.	28	185.1	6.0	8.4	2.57	2.16	2.16	27.0	2.19	0.70
	Apr.	30	205.5	6.8	8.3	2.11	1.62	1.87	20.5	2.47	0.71
	May	28	204.3	6.6	8.1	1.84	1.57	1.59	18.5	2.21	1.21
	June	25	165.5	5.5	8.1	1.89	1.25	1.25	16.4	1.59	0.92
	July	30	218.8	7.1	7.8	1.20	0.04	0.04	24.3	1.00	0.29
	Aug.	29	176.7	5.7	7.4	-0.03	-0.78	-0.73	28.7	1.89	0.68
	Sept.	15	71.3	2.4	7.4	1.20	-1.50	1.19	23.9	7.38	5.76
	Oct.	16	100.8	3.3	7.6	1.59	0.80	1.59	18.1	3.94	0.90
	Nov.	-	-	-	-	-	-	2.69	-	2.71	-
	Dec.	-	-	-	-	-	-	2.70	-	1.92	-
	Total	210	1355.3	-	-	-	-	-	-	34.21	-

PUMPAGE DATA (Cont'd)
Kawainui Swamp, Oahu
1924 to 1941

Month	KAWAINUI SWAMP PUMPAGE IN MILLION GALLONS													
	1935		1936		1937		1938		1939		1940		1941	
	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month	Total for Month	Daily Mean for Month
Jan.	-	-	6.1	0.2	76.2	2.5	-	-	-	-	-	-	-	-
Feb.	-	-	-	-	-	-	-	-	6.2	0.2	-	-	44.8	1.6
Mar.	-	-	4.1	0.1	-	-	10.0	0.3	19.8	0.6	31.6	1.0	74.4	2.4
Apr.	-	-	20.0	0.7	108.4	3.6	48.7	1.6	14.9	0.5	35.0	1.2	183.8	6.1
May	-	-	116.1	3.7	43.7	1.4	108.2	3.5	91.7	3.0	27.0	0.9	160.7	5.2
June	-	-	220.6	7.4	248.6	8.3	178.7	6.0	217.8	7.3	184.0	6.1	98.3	3.3
July	173.2	5.6	258.2	8.3	208.7	6.7	235.5	7.6	202.6	6.5	221.7	7.2	-	-
Aug.	246.3	7.9	244.2	7.9	186.5	6.0	31.3	1.0	214.0	6.9	185.7	6.0	-	-
Sept.	231.9	7.7	220.0	7.3	191.0	6.4	204.5	6.8	115.8	3.9	168.6	5.6	-	-
Oct.	44.2	1.4	114.3	3.7	101.9	3.3	117.5	3.8	69.0	2.2	57.7	1.9	-	-
Nov.	-	-	-	-	11.0	0.4	13.2	0.4	-	-	2.3	0.1	-	-
Dec.	-	-	-	-	42.1	1.4	109.3	3.5	-	-	-	-	-	-
Total	695.6	-	1203.6	-	1218.1	-	1056.9	-	951.8	-	913.6	-	562.0	-

NOTE: Data not available when not listed.